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STUDY TO DETERMINE EXTRAVEHICULAR MOBILITY UNIT (EMU) ADVANCED TECHNOLOGY REQUIREMENTS

VOL. II - TECHNICAL ANALYSES

MAY 7, 1976

NAS2-8957

Ames Research Center

Space Division
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VOLUME II

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CONTRACT NAS2-8957

AMES RESEARCH CENTER

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G. L. Wengrow
Study Manager

FOREWORD

The "Study to Determine Extravehicular Mobility Unit (EMU) Advanced Technology Requirements" was conducted for the Ames Research Center by Space Division of Rockwell International Corporation under contract NAS2-8957. The contract Technical Monitor for Ames was P. D. Quattrone, Chief of the Environmental Control Research Branch. P. D. Quattrone was assisted by H. C. Vykukal and B. W. Webbon of the same branch. Cooperation and assistance were also given by personnel at Goddard Space Flight Center, Langley Research Center, and Marshall Space Flight Center.

The final report consists of two volumes, as follows:

Volume I	Executive Summary
Volume II	Technical Analysis

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SECTION I. INTRODUCTION

The final report of the "Study to Determine Extravehicular Mobility Unit (EMU) Advanced Technology Requirements" was conducted to establish the role payloads play in design and operation of the EMU. This volume of the final report presents detailed information on the work performed in the study, including analyses of requirements that might be derived from payload design and operations characteristics, or from various EVA tasks. This section summarizes background to the study and study approaches.

1.1 STUDY OBJECTIVES

This study was planned in order to utilize previous study payloads analyses and on-going payload studies to derive EMU requirements in addition to previous physiologically and environmentally derived requirements; of particular importance in the study are requirements which might require technology advances. The stated objectives of the study are:

Identify Extravehicular Mobility Unit Technology Advances Responsive to Payload EVA Applications

Enlist Active Participation of Payload Community in Substantiating EVA Applications for Payload Operations

1.2 STUDY APPROACH

The EMU study was divided into two phases. Phase I was planned to allow for review of previous study data and to develop and test approaches for the Phase II effort. The Phase I review provided an opportunity for additional NASA direction.

Phase II of the study required investigation of EVA interfaces and reviews of payload characteristics with the payload community in several NASA centers. These reviews included efforts to validate concepts of EVA-oriented designs developed in the previous study. Using these data, design and operations analyses were performed to derive EMU requirements. The following diagram, Figure 1-1, illustrates the study approach.

1.3 BACKGROUND

1.3.1 Prior Study Activity

The study activities presented in this report were based on a contract previously conducted under the direction of Ames Research Center, entitled "Study to Evaluate the Effect of EVA on Payloads Systems".[1]

[1] Contract NAS2-8429, Final Report, Rockwell International, SD 75-SA-0028, November 1975.

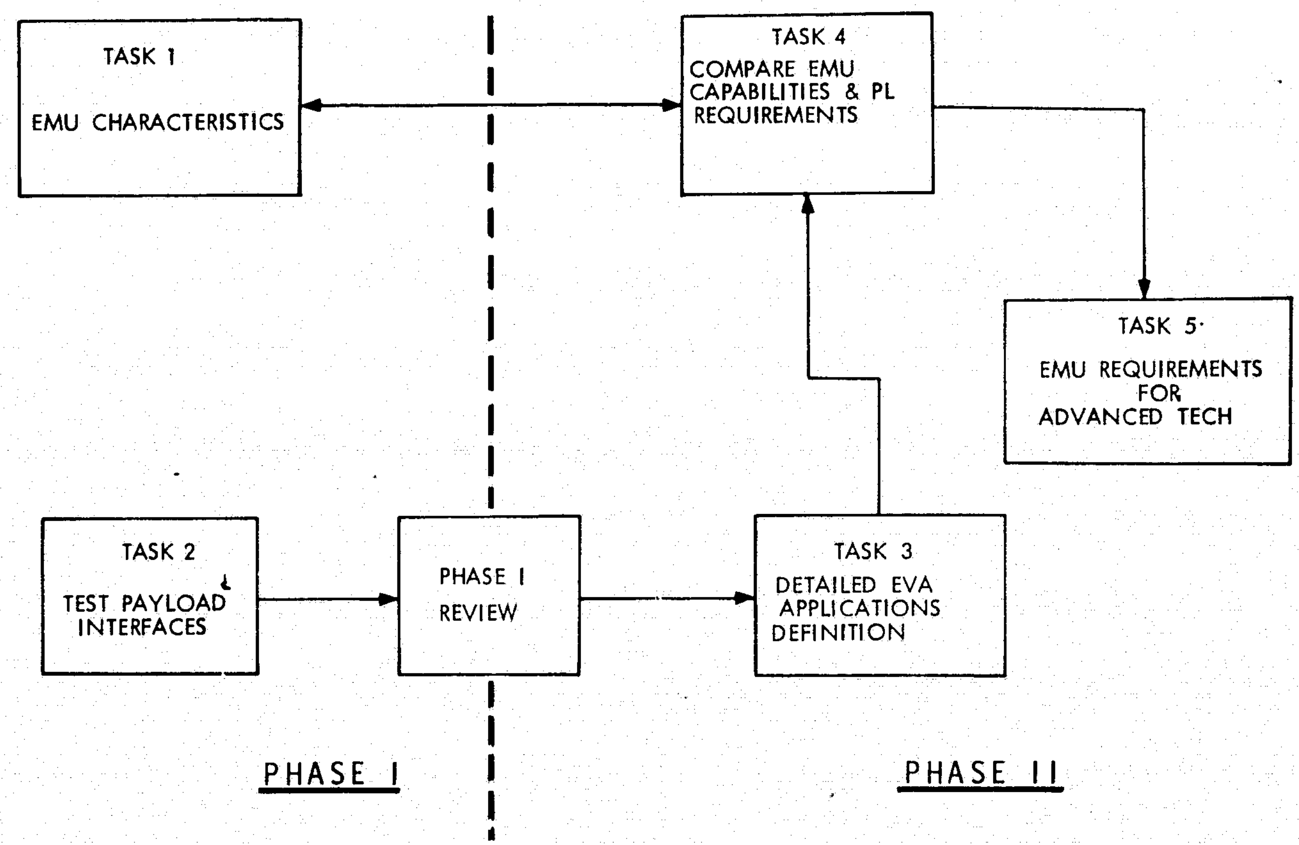


Figure 1-1. Study Approach

Study activity began with four stated objectives. Results of the study met these objectives in the following manner.

1. *Identify Uses of EVA Which Significantly Reduce Payload Costs*

The study identified 61 potential EVA applications--44 of which were Routine Operations; i.e., applied at some point in the mission cycle of every payload. Detailed design and cost data on these applications resulted typically in Net EVA savings of \$75K to \$150K for each such manual alternative. Conservatively, cost savings were only accumulated for 21 out of the total of 44 routine applications for which technical assurance and credible data could be provided.

2. *Compare Technical and Economic Characteristics of Selected Payloads--Automated, Teleoperator, or EVA-Design Oriented*

Thirteen representative payloads were analyzed in the study. Baseline (automated) modes of operation were evaluated and compared to EVA modes. In all cases, utilization of EVA resulted in design simplification and lower cots. Net savings attributed to EVA for DDT&E and first unit costs averaged \$2.5 million for automated spacecraft and \$8.9 million for sortie payloads.

3. Determine the Amount of These Savings and Extrapolate to the NASA Payload Model

Cost savings for the 13 representative payload programs were extrapolated to the total "572 flight" traffic model, whereby costs were estimated for 74 programs with 249 flight units. Net EVA savings were extrapolated to over $551M for NASA and U.S. civil payloads for routine operations. Adding DoD and ESRO payloads increases the net estimated savings to $776M.

4. Evaluate and Compare Automated Versus EVA Task Times

Detailed task-time data were applied to the 13 payloads operations to derive integrated, comparative timelines. With EVA, routine preparation timelines were decreased in one case by 1.7 elapsed hours to a maximum increase of 1.3 hours--average 0.5 hour increase. EVA durations ranged from 1.5 hours to 6 hours--average 3.7. These activities require the following:

One-man EVA - 11 payloads
Two-man EVA - 2 payloads

One EVA cycle - 9 payloads
Two EVA cycles - 4 payloads
Three EVA cycles - 1 payload (on-orbit maintenance)

Planned maintenance for a projected 13-payload program (out of a possible 51-payload programs) indicated an estimated $168M savings due to elimination of automated servicing equipment. If all spacecraft designated "Reusable" (28 programs) are included, the potentially extrapolated cost savings of the EVA mode would be ∿ $316M.

EVA savings for contingency problems of payloads were based on transport and equipment costs due to payload failures. Historical anomaly and failure data were extrapolated to the Shuttle payload model. To the extent that EVA can be applied successfully in preventing or resolving failures, reflight or jettison losses, savings up to $1.9 billion could be realized. Table 1-1 summarizes the study EVA cost savings estimates.

Table 1-1. "EVA" Study Program Cost Savings Summary

PAYLOAD MISSION ACTIVITY		Totals ($M)
ROUTINE OPERATIONS		
. Automated Spacecraft		358
. Sortie Payload		418
		776
PLANNED MAINTENANCE		
. Automated Spacecraft - LEO	168	
. Automated Spacecraft - HEO	No EVA Benefit	
		168
CONTINGENCY APPLICATIONS		
. Automated Spacecraft	1300	
. Sortie Payload	570	
		1870

1.3.2 Historical EVA Approaches

Space crew pressure garments were originally developed as a backup crew protective device, but were also seen as a developmental element for the personal protective and life support system required for projected space and lunar operations.

The Project Gemini "space walks" were experimental and were performed with a life support umbilical and a protective suit now considered extremely crude and awkward. The Apollo suits requiring a portable life support system went through several development phases before evolving into the sophisticated design which essentially served for lunar excursions, scientific instrument module activities, and the Skylab program.

Pressure suits and life support systems in the past have primarily been developed around physiological and human engineering requirements. In addition, they were primarily planned for the specific activity of Apollo lunar exploration and adapted to Skylab for ATM film retrieval. However, with the Shuttle, and its variety of payloads, a broad range of EVA tasks and activities are potential EMU design drivers. Table 1-2 compares the relative magnitude of the Shuttle program to previous manned space flight.

Table 1-2. U.S. Manned Spaceflight Data

	MERCURY	GEMINI	APOLLO	SKYLAB	ASTP	SHUTTLE
TOTAL MAN-HOURS	54	1940	7506	12,351	652	557,000
EVA MAN-HOURS	--	12	168	82	--	15,560
NUMBER FLIGHTS	6	10	11	3	1	572
CREW SIZE	1	2	3	3	3	~4

The Shuttle EVA manhours are predicted from the EVA study. If the total Apollo and Skylab manhours-to-EVA manhours were ratioed to Shuttle total man-hours, the results would be 12,500 Apollo, and 3,700 Skylab EVA manhours. The baseline Shuttle provides the equivalent provisions for 20,600 manhours of EVA for 572 flights--over 13,700 for payloads usage.

The Apollo program EVA hours were driven by the primary mission objectives of lunar exploration. Skylab did not have as high a ratio of EVA man-hours to total mission man-hours because of the very long duration crew stay times. However, planned EVA was conducted on "payload" (ATM) type operations as opposed to the more unique lunar exploration activities of Apollo. It is significant that about 60 percent of Skylab EVA man-hours were conducted for contingency purposes. Over 15 thousand man-hours of payload-related operations can be predicted from the "EVA" study. This represents a higher percentage of total EVA man-hours than either Apollo or Skylab, but correlates approximately with Shuttle orbiter-provided EVA for payloads. Contingency EVA man-hours could increase this total by a factor of two or three.

The significance of these data are that they emphasize the overall importance of EVA for Shuttle payload operations and, therefore, the importance of ensuring an efficient and effective EVA capability.

1.4 SUMMARY OF STUDY RESULTS

The study began with two stated primary objectives. Results of the study in relation to these objectives are discussed in the following paragraphs.

Identify EMU Technology Advances Responsive to Payload EVA Applications

In examining the interface of EVA crewman-to-payloads, requirements were seen to fall into three groups:

1. Crew protection (from EVA task or payload-related hazards)

2. Crew performance (related to payloads tasks)

3. Payload protection (from EVA-payload tasks)

Twenty requirement categories were identified in these three groups. Requirements for the EMU were then derived in these categories from four primary sources: payload design characteristics, payload missions and operations, EVA tasks, and EMU design characteristics. A matrix of these requirement categories and derivation sources is shown in Table 1-3.

Each requirement category was evaluated on the basis of payload definition and EVA operations. The nature of some types of requirements lend themselves to quantitative conclusions. Quantitative data are presented in this report relative to the following requirement categories:

Thermal - payload temperature
Radiation Exposure - payload source levels and mission EVA exposures
to the Van Allen belt
Penetration and Impact Resistance - payload preferred design approaches
Force Interfaces - EVA task reaction force estimates
Operating Time - mission/EVA statistical data
Contamination - payload sensitivity

Other evaluations provided subjective results. In other cases, no payload unique requirements were derived.

Table 1-3. Matrix of Requirements Types/Derivations

REQUIREMENT CATEGORY	DERIVATION SOURCE			
	PAYLOAD DESIGN	PAYLOAD MISSION	EVA TASK	EMU OPNS.
I. CREW PROTECTION				
1. Flammability	X			
2. Thermal	X	X	X	
3. Durability	X	X	X	
4. Dielectric properties	X			
5. Radiation resistance	X	X	X	
6. Penetration, abrasion resistance	X			
7. Fluid resistance	X			
8. Impact resistance	X		X	
9. Bio-contamination	X			
II. CREW PERFORMANCE				
1. Reaction time	X			
2. Force interfaces	X		X	
3. Mobility	X		X	
4. Visibility/orientation	X			
5. Communications	X			
6. Operating time	X			
7. Reliability/maintainability			X	
III. PAYLOAD PROTECTION				
1. Contamination	X			X
2. EMI/EMC				X
3. Dielectric properties	X		X	X
4. Surface damage				X

Enlist Active Participation of Payload Community in Substantiating EVA Applications for Payload Operations

In addition to earlier reviews conducted during the "EVA" study, a specific presentation was planned and conducted to meet this study objective. Meetings were held with personnel at Space Division who are participating in the following payload study contracts:

Payload	Contract	Cognizant Center
LANDSAT (EOS)	NAS5-23203 (Basic)	GSFC
ATL	NAS1-14116	LaRC
ASP	NAS5-23203 (Mod 16)	GSFC

The space telescope was also reviewed with investigators responsible for recent IR&D and payload integration studies. The review at NASA centers included the following project areas:

Goddard Space Flight Center

Shuttle Payloads Office - Multi-Mission Modular Spacecraft (MMS)
- Astronomy Spacelab Payloads (ASP)

Langley Research Center

Shuttle Experiments Office - Advanced Technology Laboratory (ATL)

Marshall Space Flight Center

Program Development - Preliminary Design
Science and Engineering - Systems Analysis and Integration

The results of these reviews can be summarized as follows:

- *Planned Use of EVA Offers Attractive Design Alternatives in Cost Savings, Simplicity, and Reliability*
- *Payload Designers Require Assurance of Reasonable EVA Performance*
- *EVA-to-Payload Interfaces Are Not Adequately Understood by Payload Designers and Require Further Study*
- *Lack of Definition of Shuttle Provisions (i.e., Multi-Mission Equipment) and User Charge Policies Has Resulted in Uncertainty in Payload Design*

Two general conclusions from these reviews are: (1) that the uses and methodology for EVA are not well understood nor applied, and (2) that there are concerns about costs and imposed qualification and documentation requirements. Some of the more specific potential requirements areas are as follows:

- *Payload edge "sharpness" requirement on EMU*
- *Visibility capability over lower body*
- *Glove dexterity and "fit" in payload designs*
- *Thermal interface on polished aluminum*

SECTION II. PAYLOAD ANALYSES

In order to ensure concentration of study activities, the representative payloads to be examined were limited to five, in comparison to 13 payloads analyzed in the "EVA" study. Analyses conducted were generally limited to those payloads; however, where pertinent characteristics (e.g., cryo-cooled sensors, RTG's, etc.) were not found in the representative payload, such data were added to the study from other payloads. In addition, other results and data from the "EVA" study were used, including detailed equipment designs, overall payload definitions and operations data, and mission traffic model data.

2.1 REPRESENTATIVE PAYLOADS AND EVA CONCEPTS

The five representative payloads and their responsible center are:

Payload	Responsible Center
Atmospheric, Magnetospheric, and Plasmas in Space (AMPS)	MSFC/GSFC
Space Telescope	MSFC
LANDSAT-D (EOS)	GSFC
Astronomy Spacelab Payload (ASP)	GSFC
Advanced Technology Laboratory (ATL)	LaRC

The payloads listed were selected to meet the following criteria:

1. At least one payload from the payload centers of MSFC, GSFC, and LaRC

2. Payloads studied in the previous EVA contract or which are the subject of currently contracted in-house studies

3. Payloads which reflect a wide range of candidate EVA tasks

A description of each payload and its typical EVA applications follows.

2.1.1 Atmospheric, Magnetospheric and Plasmas in Space (AMPS)

2.1.1.1 Baseline System

The AMPS payload consists of a variety of active and passive instrumentation designed to observe and artificially perturb the space environment and upper atmosphere. Multipurpose controls, displays, and data processing equipment are included to permit effective interaction among on-orbit investigators and experiments. A typical configuration for the AMPS payload might include: (1) a sortie lab module, (2) a pallet (with at least three sections), and (3) scientific equipment. Controls/display units are located in the Spacelab module, while all the sensors are pallet mounted.

2.1.1.2 Baseline Payload Operations

The AMPS payload is a complex integration of a variety of sensors and supporting devices. Consequently, it was felt that the most probable sequence for deployment would be by generic or grouped sensors. To satisfactorily perform the AMPS mission many of the sensors are operated simultaneously to take advantage of the synergistics effect and obtain backup information. Since most of the sensors operate simultaneously in many of the experiments, it was felt that no experiment should be started until all items were deployed, checked out, and activated. Preparation for operation has been analyzed from the viewpoint of deploying those most likely to be either hazardous or require some time to separate/translate from the Shuttle or immediate Shuttle vicinity.

2.1.1.3 AMPS EVA Applications

The major EVA effort is exerted during both the preparation for operation and the preparation for entry. Since most of the equipment is so large or generates large amounts of radiation, the normal mission experiment operations are conducted from the control and display area. Use of EVA has allowed simplification of some equipment such as replacing deployable booms with stowed tubular masts. The major benefit derived from EVA is simplification of Shuttle-to-payload interfaces. Figure 2-1 illustrates the overall payload and a typical EVA-to-payload interface.

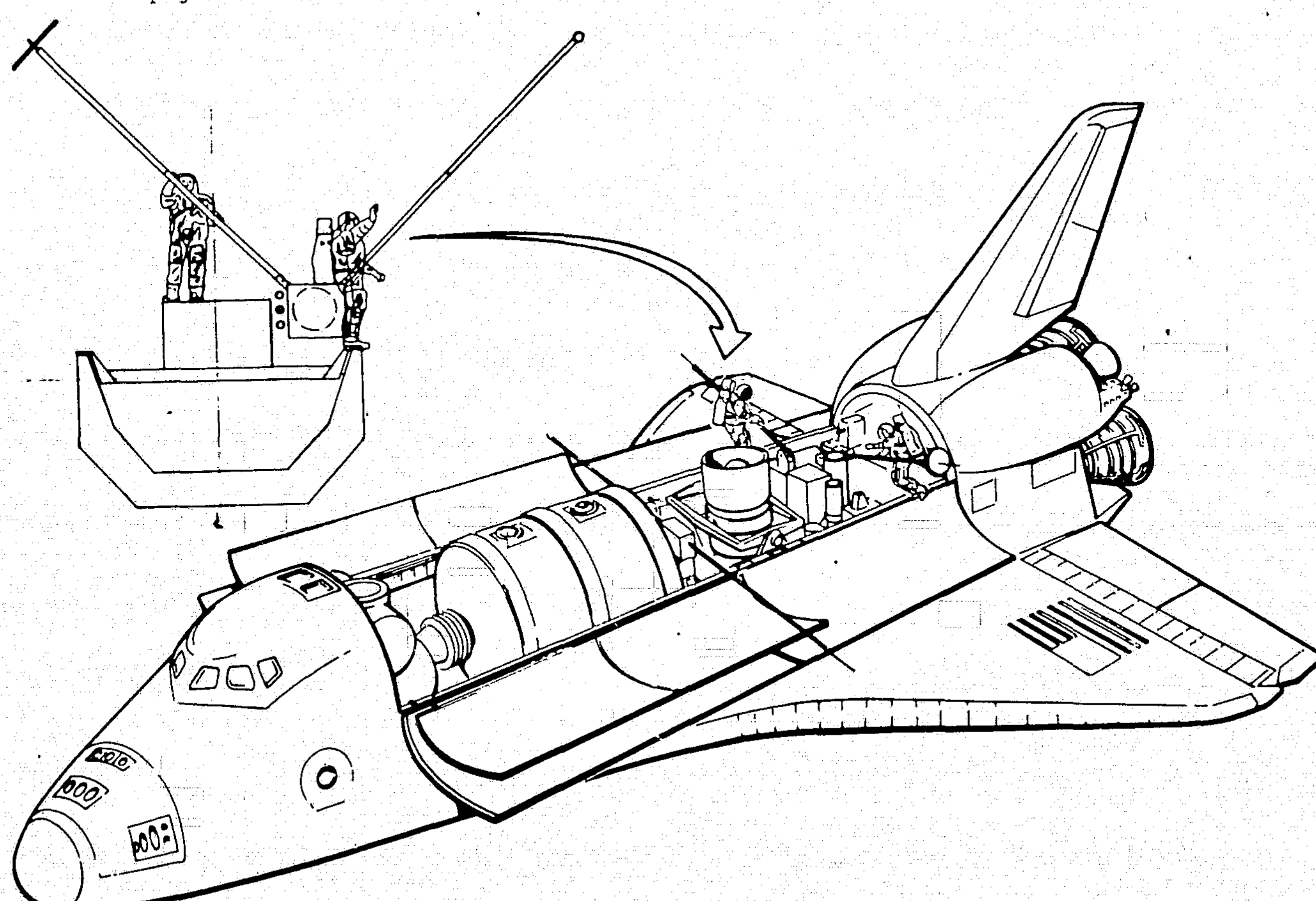


Figure 2-1. AMPS EVA Operations

The same sequence of equipment deployment is used in the EVA mode as in the automated. That is, deployment of the most sensitive/complex units first (i.e., subsatellites and balloons, then large deployable structures).

Evaluation of tasks and times shows that many of the less complex installations can be performed simultaneously. The boom system and the satellite system are not compatible for simultaneous deployment. By their very nature the satellites once released are free to move about and not having a total field of view of both satellite and the deployed antennas, it can become a sensitive situation. The following provides a scenario of EVA operations.

Deployable Units - AP600. The EVA crewman performs a visual inspection for damage or defects of the balloon canisters and the multi-sized barium canisters. Following a successful inspection the packaged balloons are deployed into space. The balloon deployment mechanism is a simple mechanical device which is spring-loaded. It requires only that the astronaut pull a lever. As the balloon canister is deployed, a timer attached to the canister sets off the inflating mechanism at the proper time. Both balloons are deployed within a few minutes of each other, but are positioned such that they translate away from the Shuttle and away from each other.

The EVA crew performs a physical inspection of the selected satellite. Having found no discrepancies one EVA astronaut provides vernier guidance to the remote manipulator during manipulator-to-satellite attachment. The other astronaut translates to the satellite latching mechanism in preparation for deployment.

Upon disengagement of the satellite from its pallet mount, both EVA astronauts help guide the unit and dampen any induced oscillations. The manipulator is operated from the RMS station temporarily using a Shuttle crewman. The manipulator is then extended such that the satellite is the maximum distance from any point of the Shuttle and releases the satellite.

Boom System - AP500. Each of the two 50-meter booms retain the astromast design and the requirement for articulation in two planes, remaining remotely deployable and maneuverable, but the platforms are prepared by two EVA astronauts. The astronauts retrieve two matched sections of a 5-m tubular pole, assemble it via the quick disconnect-type connector, and one of the astronauts inserts the assembled unit into its proper operational fitting. This same sequence is followed assembling a second deployed 5-m experiment boom. All electrical connections are then made.

Next, one astronaut removes the contamination covers from appropriate instruments and unlatches all mechanisms as required plus unlatches the gimbal platform. The other astronaut unlatches the retention mechanism on the Boom A canister. The 50-m boom is then remotely deployed at a rate of 5 to 6 feet per minute. Another remotely performed function is activated to drive out two 33-meter dipole antennas mounted on the sides of the experiment platform. At this time the platform is well clear of any Shuttle appendages and the dipoles can be freely deployed.

The astronauts translate to Boom B where the contamination-sensitive sensors (targets and calibration light) have their covers removed and stowed and the gimbal platform unlatched. In conjunction with the above task, one astronaut begins to unlatch Boom B latching mechanisms. When all latching mechanisms have been released (Boom B and platform), Boom B is then extended in the same manner and at the same rate as Boom A.

Transmitter/Coupler System - AP400. Preparation for operation is identical to the automated procedure with the exception that the contamination cover is removed manually and stowed. The interface between the antenna control mechanism and the C&D panel is substantially simplified with the removal of motor drives, limit switches, talkbacks, wires, and the like.

Lidar System - AP200. The lidar system is basically a laser user integrated into a gimbaled contamination container. The astronaut activities will be to remove contamination covers, orient the lidar from its launch position to its normal operating position, and to remove gimbal latching devices.

Gimbal Accelerator System - AP300. The gimbal accelerator system is quite similar to the lidar system in that the EVA task only consists of removing and stowing a contamination cover and removal of gimbal latches.

Remote Sensing Platform - AP100. Preparing the remote sensing platform for operation requires that an astronaut verify that the canister pressure has vented down to the ambient conditions; if not, then he will open a vent valve and ensure evacuation. The astronaut unlatches each of the mechanical devices. He then removes the contamination cover and transfers it to the second astronaut who secures it to a designated fixture. With the cover stowed, the astronauts position the sunshield by manually extending it to its limit. Final EVA activity consists of unlocking the gimbal mount. Each astronaut unlatches two of the mechanisms closest to his station.

2.1.2 Space Telescope (ST)

The ST is classified as a current design reusable payload with the design compatible with on-orbit servicing as well as retrieval and refurbishment on earth.

2.1.2.1 Baseline System

The object of the ST program is to utilize the large high quality telescope and a variety of complementary instruments to provide astronomical observations that are not possible with ground-based telescopes. Observations in the ultra-violet and infrared regions of the spectrum will be emphasized. The specific observational program for the ST is still being planned. It is planned that a single instrument can be utilized during the 1980-1991 time period by use of periodic on-orbit servicing and less frequently, return to earth for refurbishment. The study schedule calls for telescope delivery to 28.5 deg inclination, 520 km orbit.

Servo drive mechanisms are provided to drive the telescope sunshade to its extended position and provide for opening of the sunshade aperture door. A flexible power and ground umbilical between the spacecraft and orbiter is utilized in order to allow movement of the spacecraft prior to release from the orbiter. An automated umbilical release and reconnect device will be required. Automated deployment systems are provided for spacecraft solar panels and communication antennas. These will be actuated after the LST is deployed to the point of clearing the orbiter structure.

2.1.2.2 Baseline Payload Operations

Delivery Missions. Following a visual inspection of the payload using the orbiter CCTV systems, ST boost locks will be released and the spacecraft rotated to allow extension of the telescope sunshade. At this time the solar arrays and communication antennas can be deployed and test and checkout of subsystems started. The complexity of the telescope and its instrumentation requires an extensive checkout time interval prior to release of the payload from the orbiter. A 48-hour quiescent period prior to opening the telescope cover is recommended. This will allow contamination clearing and the establishment of thermal equilibrium in the telescope structure. After cover opening another period of ST operations checks will be performed. After satisfactory completion of checkout, the ST separation operations will be performed.

Servicing Missions. ST design concepts have included the use of a modular subsystem and component arrangement with provisions for manual, EVA servicing. Special module exchange mechanisms, possibly activated through the RMS system, would be a requirement for automated servicing and exchange of components in the scientific instrument package (SIP) and the support systems module (SSM) of the ST, though such systems are not required by the current baseline concept.

Retrieval Missions. The ST study schedules call for a first retrieval and ground refurbishment of the spacecraft after one year of on-orbit operations and a second refurbishment after an additional 1-3 years of on-orbit operations. Capture and docking operations will be identical to the same activity of the servicing mission. Preparation for return will include automatic retraction of the ST sunshield, closing of the sunshield cover, retraction of solar panels, and retraction of the communication antennas. These activities must be completed before the ST can be rotated completely into the payload bay. After rotation into the bay, the entry latches will be fastened.

2.1.2.3 ST EVA Applications

EVA can eliminate cert[illegible] of the automated devices for deployment and retraction of spacecraft eq[illegible]pment. The discussion of the EVA concepts for payload delivery, payload servicing, and payload retrieval missions for the ST are given below. The ST payload and typical EVA applications are illustrated in Figure 2-2.

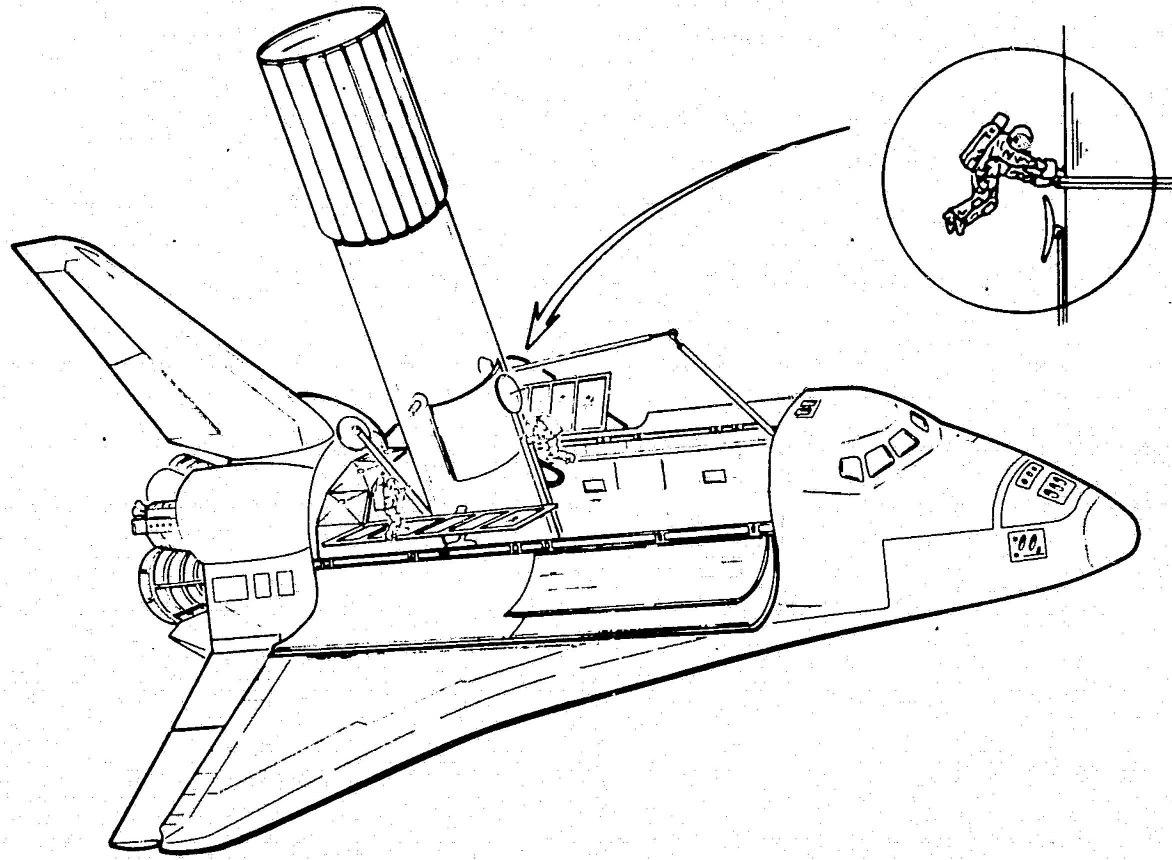


Figure 2-2. ST EVA Operations

Delivery Missions. Boost latch release for the ST remains an automated operation because it is a Shuttle-provided function. For EVA operations, the ST should be rotated out of the payload bay as shown in the figure. Major EVA activities identified for preparation of the ST include sunshade extension, deployment of solar arrays, deployment of communication antennas, and disconnection of the orbiter-to-payload umbilical. EVA operations also include items such as release of the boost locks of the extended devices, sunshade cover, and inspection of the spacecraft prior to deployment. The long duration test and checkout operations for the ST are performed in the automated mode. The EVA crew egresses again after checkout tests are completed to assist in the umbilical removal and final separation operations.

Servicing Missions. EVA operations are utilized for retraction of extended devices to the extent necessary prior to EVA servicing. EVA is also used to connect the orbiter-to-spacecraft umbilical, inspection of spacecraft, installation of safety items, and access of the spacecraft spares.

Retrieval Missions. The EVA-oriented retrieval mission operations for the ST are similar to the servicing mission operations described above relative to rendezvous, capture, and docking with the spacecraft. Instead of the servicing operations, the ST will be prepared for entry. EVA activities include securing extended devices, inspection of the spacecraft, and attachment of the orbiter-to-spacecraft umbilical. These activities will be accomplished prior to rotating the ST entirely within the orbiter payload bay.

2.1.3 LANDSAT/MMS

2.1.3.1 Baseline System

This payload exemplifies a low cost reusable design. The payload is installed in the orbiter together with an automated module exchange mechanism for on-orbit servicing. The MMS design concept consists of "standard bus" modules for spacecraft functions, with various configurations of special mission equipment mounted on a forward structural ring. The objectives of the program are to continue a wide ranging program of earth observations to support the long range goals of scientific disciplines such as agriculture, geology, meteorology, hydrology, and oceanography.

Major payload sensors for the representative payload include the (1) thematic mapper, (2) radar imager, (3) high resolution imager, and (4) pollution monitoring package. The on-orbit support equipment consists of two major elements, (1) the payload retention and positioning system which holds the payload in the orbiter during ascent and then rotates the payload out of the payload bay, and (2) the special purpose manipulator system which is used for module exchange on servicing missions.

2.1.3.2 Baseline Payload Operations

The MMS earth observations program will operate a sequence of satellites in sun synchronous orbits starting in 1979.

Delivery Missions. The automated approach to LANDSAT activation and checkout will start with preparation of the orbiter payload specialist station. A visual check of the payload may be made using closed circuit television installations in the orbiter bay and on the remote manipulator system. Checkout of certain payload sensors and subsystems can be made while the payload is in the stowed position. The positioning platform will then erect the payload out of the orbiter bay to a vertical position. Solar panel erection and unfolding and radar antenna extension will be verified. These items will be returned to a stowed configuration prior to payload boost to operational orbit. Contamination shields of payload subsystem optical components will be opened.

Maintenance Missions. The MMS flight support system (FSS) concept has been developed to provide an automated on-orbit servicing system. The basic concept of the FSS is the exchange of major modules of the spacecraft subsystems and mission (payload sensors) equipment.

The automated routine of MMS capture and docking operations begin with preparation of the FSS and RMS control. The boost locks on the FSS will be released and the payload positioning platform rotated to the vertical orientation to receive the spacecraft. The orbiter RMS will be attached, and the LANDSAT maneuvered into position to be captured by the positioning platform docking latches. During capture the Shuttle-to-payload umbilicals will automatically be attached.

Major maintenance functions will be performed by the FSS module exchange mechanism (MEM). The appropriate spare modules in the FSS storage compartment will be removed by the MEM, elevated to the payload module position where the MEM will withdraw the used module, replace it with the new module, and then return the expended module to the storage compartment. The procedure will then be repeated until all the required payload module replacements have been accomplished. Certain payload component replacements (e.g., the radar antenna) will require the use of the RMS in the component interchange.

Retrieval Missions. After the planned mission is completed or after system malfunction for which on-orbit maintenance is not practical, the spacecraft will be retrieved and returned to earth for major refurbishment activities. The capture and docking operations for retrieval will generally be identical to that of the similar activity of the routine servicing missions.

2.1.3.3 LANDSAT EVA Applications

The EVA-oriented design and operations maintain the design and function of the baseline automated flight support system as well as that of the spacecraft itself. The basic LANDSAT configuration and typical EVA applications are illustrated in Figure 2-3.

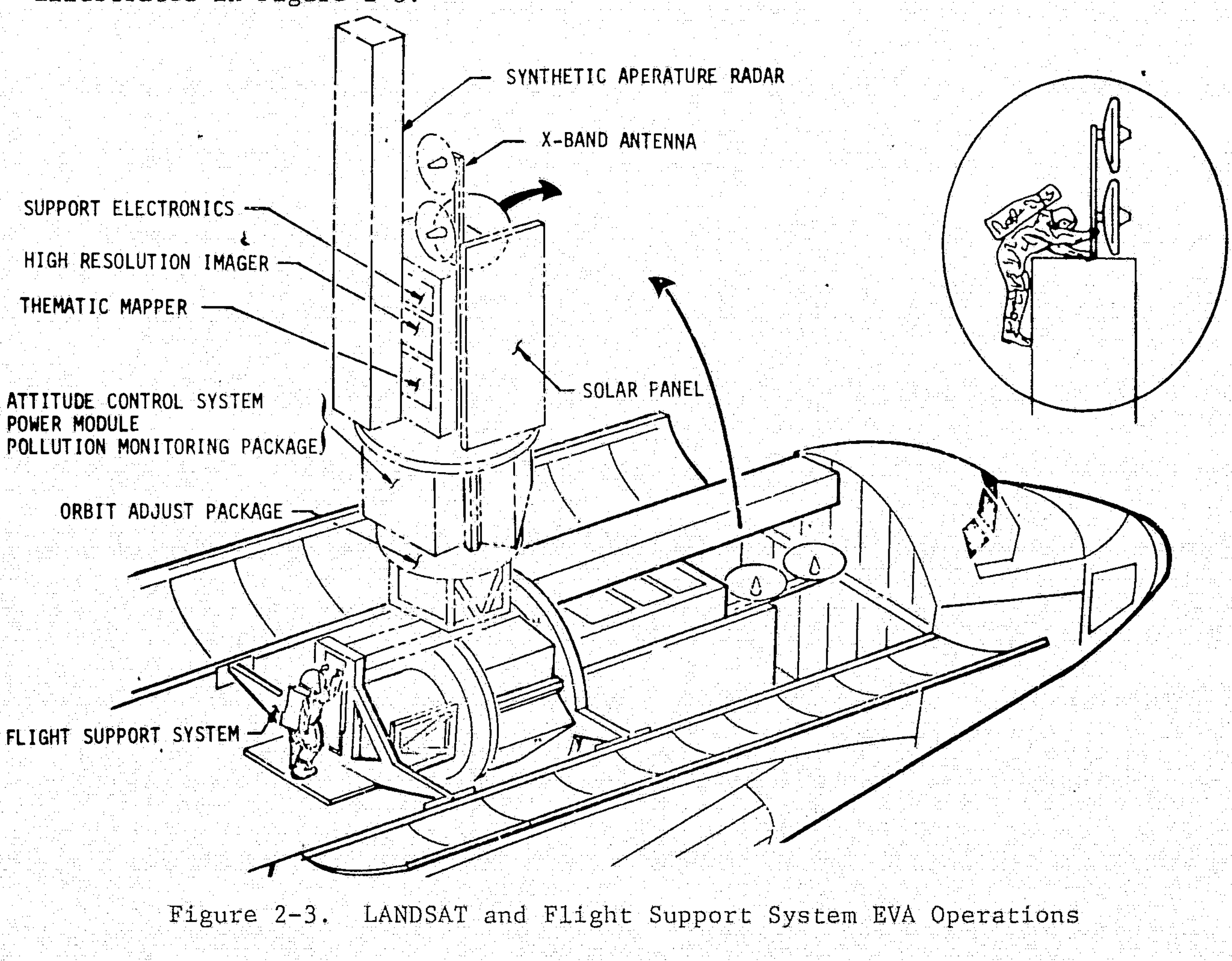


Figure 2-3. LANDSAT and Flight Support System EVA Operations

Delivery Missions. One function is performed in the stowed position. The EVA concept for this operation would be to use a portable power tool to rotate the erection platform (and attached spacecraft) out of the orbiter payload bay into a payload release position. These functions could be performed by EVA as either a primary mode or as a backup.

Preliminary payload activation and checkout are the same in the EVA modes as in the automated mode of operations. EVA activities are subsituted for automated device operations in the release of boost latches and monitoring of the checkout of mechanical systems.

The major EVA substitutions in payload activation operations involve EVA utilization of a portable power tool in place of built-in automated mechanisms in the release of the payload and in the rotation of the payload positioning platform. The deployment of the payload and separation from the orbiter will be accomplished in the same manner as with the automated system.

Maintenance Missions. The EVA-oriented approach to maintenance utilizes the portable power tool and monitoring and alignment adjustments in the module exchange operations. A design concept for manual replacement of the communication antenna on the MMS resulted in simplified mechanization compared with baseline RMS operations. EVA capability also is better able to cope with minor repairs and adjustments discovered during detailed visual inspection of the spacecraft.

Retrieval Missions. The retrieval operations are the same as those required for servicing operations described above. The operations utilize manual operating latches for securing the payload and appendages for entry. EVA inspection and installation of contamination shields and safety devices replace the automated systems for these activities.

2.1.4 Stellar Astronomy Spacelab Payload (ASP)

2.1.4.1 Baseline System

The stellar configuration for ASP is typical of several all-up cargo bay concepts currently being evaluated for Shuttle integration. The various science sensors are installed on five pallet sections in the cargo bay of the orbiter. Typically, three sets of Small Instrument Pointing Subsystem (SIPS) gimbal installations are installed one to a pallet. Each SIPS provides an erection capability and mounting for two canisters with independent gimbaling. Each of the six canisters contains selected compatible sensors for celestial investigations. A large (one meter) UV optical telescope is mounted on the two remaining pallets and operated on an ESA Instrument Pointing System (IPS). Primary objectives of the payload are to obtain UV imagery surface brightness and spectra in a range of radiation bands.

2.1.4.2 Baseline Payload Operations

Operations for the SIPS-mounted canisters will consist basically of remote release of retention latches of the erection mechanisms and gimbals, followed by erection of the units above the Shuttle moldline. Sensor covers will be opened and various checks on calibrations will be performed before initiating programmed operations.

The UV telescope will be engaged to the IPS, then released remotely from its boost retention latches. Subsequently, the telescope will be erected and prepared for operation.

2.1.4.3 ASP EVA Operations

Figure 2-4 illustrates the ASP stellar astronomy payload and typical EVA interface.

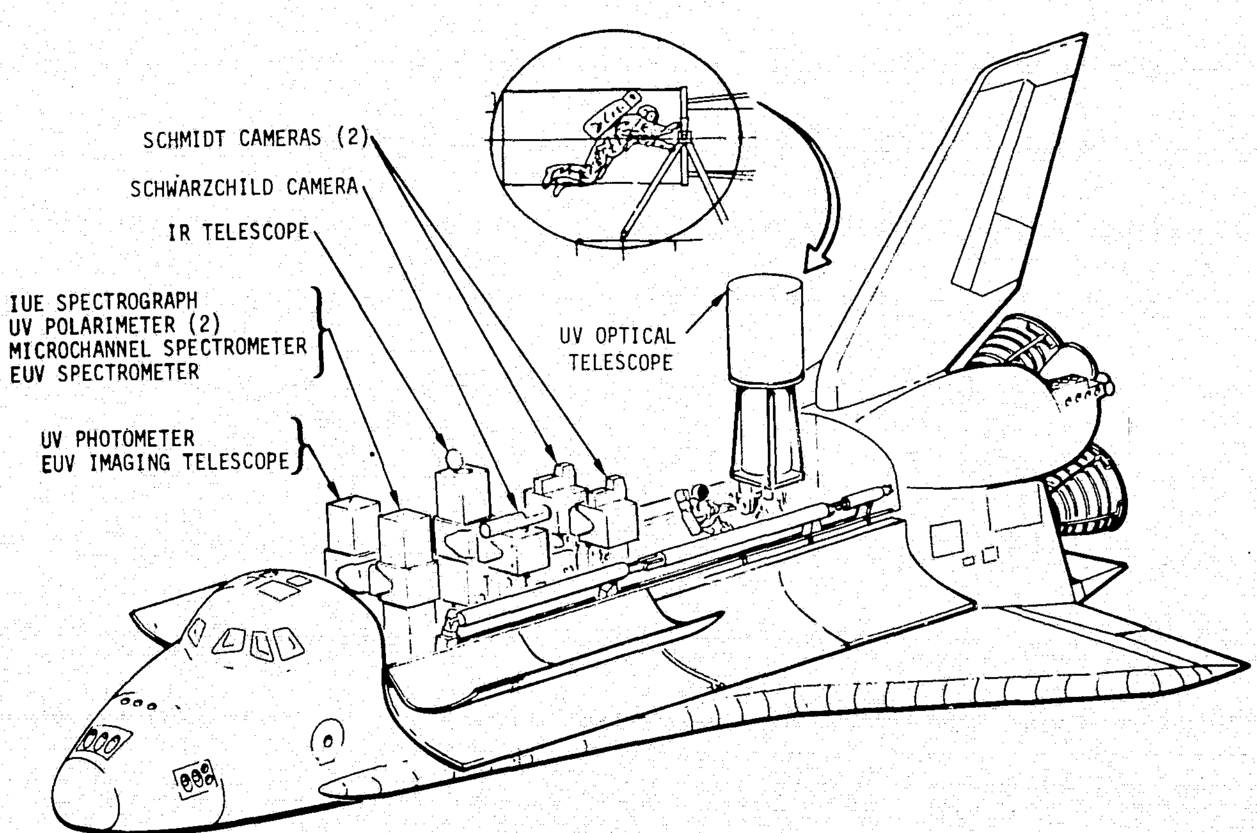


Figure 2-4. ASP EVA Operations

In preparing the payload for operation, the EVA crewman would most likely start with the UV telescope, and manually engage the IPS and umbilical connector to the telescope. Next, the three flight support latches would be released with manual over-center latch mechanisms. The boost protective cover for the telescope could be manually released and stowed. Finally, the crewman would observe the remotely commanded telescope erection to ensure clearance control.

Proceeding forward through the bay to the two SIPS-mounted Schmidt camera canisters, the crewman will remove the two optics covers, unlatch four locks on the gimbals, and release boost latches on the erection mechanism. A portable drive motor will then be engaged to the erection mechanism to raise the SIPS assemblies out of the cargo bay.

The next two SIPS assemblies will then sequentially be prepared for operation in the same manner.

2.1.5 Advanced Technology Laboratory (ATL)

The ATL is a series of dedicated 7-day sortie missions consisting of a multi-disciplinary payload mounted on standard Spacelab pallets or in combination with the Spacelab module. The payload contains combinations of such disciplines as navigation, earth observations, physics, and chemistry, and environmental effects on material.

2.1.5.1 Baseline System

A two-section pallet utilizes the aft portion of the Shuttle bay. Controls and displays are located internally in a short Spacelab module. The ATL payload selected for the "EVA" study was defined in the SSPD study as "ATL P/L No. 5 (pallet only), ST-23S". The data from that study were modified here to reflect current studies defining various experiments on payloads 1-3. The payload consists of a variety of pallet-mounted experiments.

2.1.5.2 Baseline Payload Operations

Following orbit establishment and a sleep period, the Spacelab is activated and the ATL experiments equipment deployment begins. The ATL payload pallet-mounted equipment can be deployed sequentially and operated as required for the duration of the mission. The experiments in some cases can be operated without man-interface. The baseline mission operation is performed totally from the Spacelab module.

2.1.5.3 ATL EVA Applications

The major areas of EVA applications are in the pre-operations phase where a substantial amount of EVA is used to deploy the various sensors. The EVA activity required to support pre-operations functions requires, at a minimum, two astronauts in space suits and at least one in the Shuttle cabin at the PS station. Figure 2-5 illustrates typical experiments for ATL and EVA interface applications. The following represents typical EVA tasks.

Microwave Interferometer. The microwave interferometer cruciform deployable-boom system requires two astronauts. Upon egressing from the airlock, the astronauts position themselves to observe the deployment process. A hand-held power unit is attached to the boom drive system by one astronaut while the other unlatches the boom tips from the individual boom canisters. Two opposing booms are deployed simultaneously. This allows each astronaut to observe one boom arm as it deploys. Upon deployment, the remaining opposed booms are deployed.

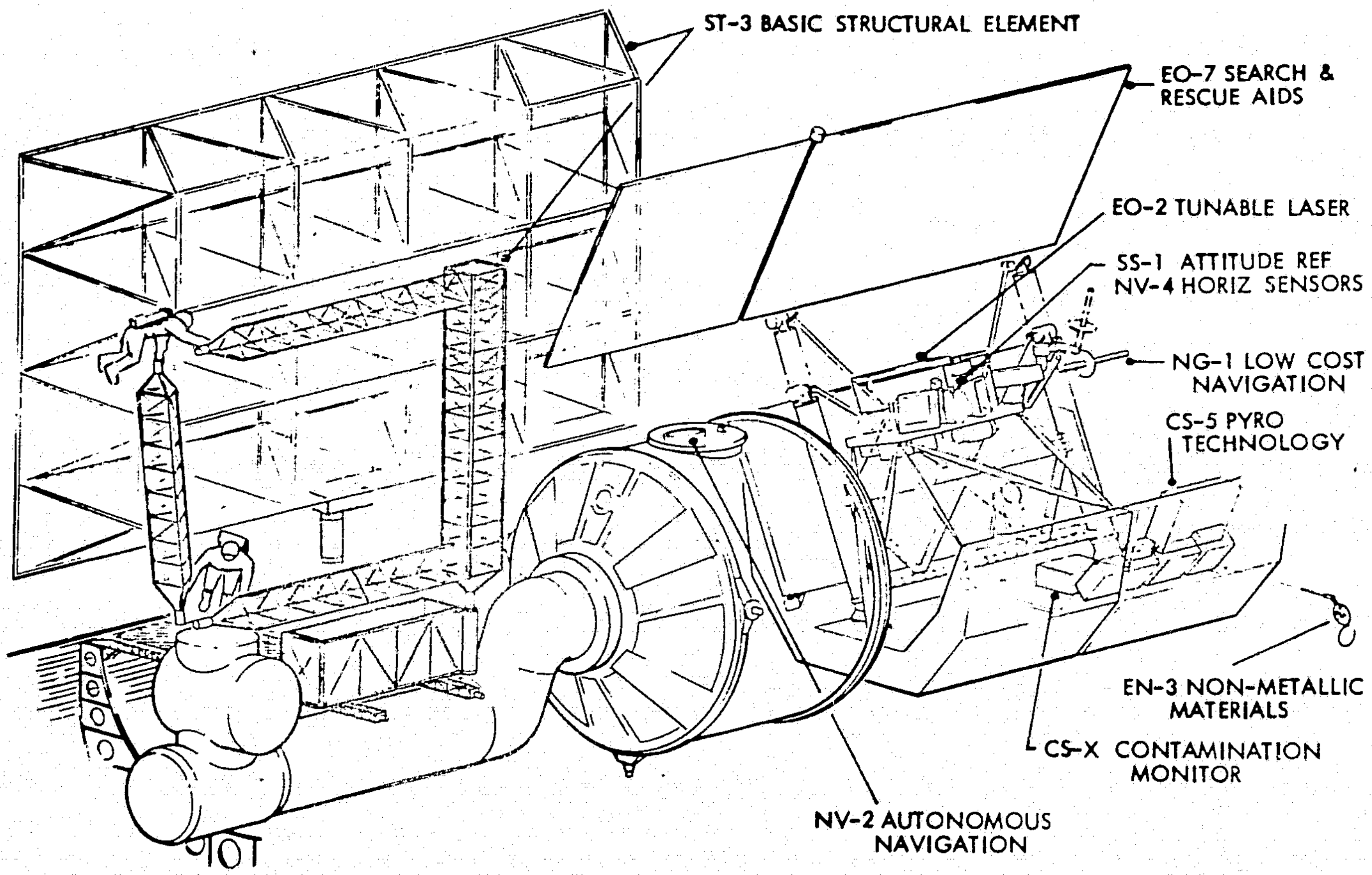


Figure 2-5. ATL EVA Operations

Search and Rescue Aids. From work station 2, one astronaut moves to the large side-looking radar antenna and positions himself at that work station. The other astronaut moves to the various antenna boost locks and proceeds to unlatch each one. Once unlatched the long slender antenna is manually rotated outward into its operational position, unfolded, and the antenna itself is properly angled if required by the astronaut.

Molecular Beam Facility. The neutral gas measuring device is stored in an evacuated container prior to launch to maintain maximum cleanliness. One astronaut removes and stows the contamination cover. He then unlatches all boost latches on the device within the container. After completion of the unlatching task, the sensor device, which is mounted at the end of a 23-m (75 ft) boom, is driven outward using an astronaut hand-held power drive unit. Once the unit is deployed, the boom system is locked in place.

Ultraviolet Meteor Spectroscopy. One astronaut vents the contamination container, removes and stows the cover, and inspects the unit for obvious damage or contamination on the camera and UV spectroscope lens. In addition, he will load film as required.

Autonomous Navigation. One astronaut vents any residual pressure in the contamination chamber and the other positions himself to unlatch the contamination covers, remove and stow. The equipment is then inspected visually. The astronaut on the unit them removes the gimbal system boost latches.

Lidar Measurements of Cirrus Clouds. One astronaut positions himself in the foot restraints, and begins by venting the contamination container. The cover latches are unlatched and the cover is removed and stowed. After performing a visual inspection of the unit, he then removes the boost locks on the gimbal system.

Non-Metallic Materials Experiment. One astronaut removes the contamination cover exposing the specimen and unlatches the boost latches. Using the hand-held power drive tool, he extends the specimen tray the prescribed height.

2.2 PAYLOAD CHARACTERISTICS/EVA INTERFACE

Each representative payload was analyzed to determine physical characteristics and potential impact on EMU requirements. These data were assembled into formats to assist in reviews with in-house and NASA payloads personnel. Each set of data sheets is presented below.

2.2.1 Atmospheric, Magnetospheric and Plasmas in Space (AMPS)

I. PAYLOAD DESCRIPTION (Reference Drawing No. 4260-122)

A. Atmospheric, Magnetospheric and Plasmas in Space (AMPS)

B. NASA Headquarters - PHY-7; SSPD - AP-06A

C. Atmospheric and Space Physics

D. Spacelab and Pallet

E. Consumables - GN_2, LN_2, Film (30 kg) (66 lb)

F. Orbits - 28.5/90 degrees inclination, 320 to 500 km (173 to 270 nm)

II. SUMMARY OF CANDIDATE EVA TASKS

A. Deployable Satellites

1. Unlatch satellite boost locks
2. Assist attaching RMS to satellite
3. Assist placement of satellite after recovery
4. Secure satellite entry latches

B. Boom System

1. Assemble two 5-m pole booms; install into Boom A platform
2. Unlatch Boom A boost locks
3. Unlatch Boom B boost locks
4. On entry, reverse (3), (2), and (1)

C. Transmitter/Coupler System

1. Remove contamination cover
2. Deploy dipole antenna using hand-held power unit
3. Reverse (2) and (1) for entry

D. Lidar System

1. Depressurize lidar canister
2. Replace lidar boost latches
3. Store canister cover
4. Reverse (1), (2), and (3) for entry

E. Gimbaled Accelerator System

1. Remove contamination covers and stow
2. Reverse for entry

F. Remote Sensing Platform

1. Vent RSP container
2. Unlatch, remove, and stow RSP cover
3. Deploy sunshield
4. Release gimbal

III. EVALUATION OF EVA INTERFACES

A. Structures

1. Twist, push and pull latches and boost locks
2. Handhold near each latch and/or lock in excess of 0.6 m (24 in.) Foot restraints required when handhold cannot be accommodated
3. Handholds must support a push/pull torque of 34 N-m (300 in.-lb) and foot restraints 170 N-m (1500 in.-lb)
4. Personnel belt restraints required during equipment assembly (i.e., boom system - 5 m pole boom installation)
5. Removal of contamination covers and stowage. Covers range from 0.15 m (6 in.) to approximately 1.93 m (∿76 in.)
6. Astronaut body access between equipment

B. Removable Modules (Maintenance)

1. Remove/replace electronics from

a. Remote sensing platform

- Spectrometers
- Radiometer
- Interferometer
- Photometer
- Cameras
- Particle detectors

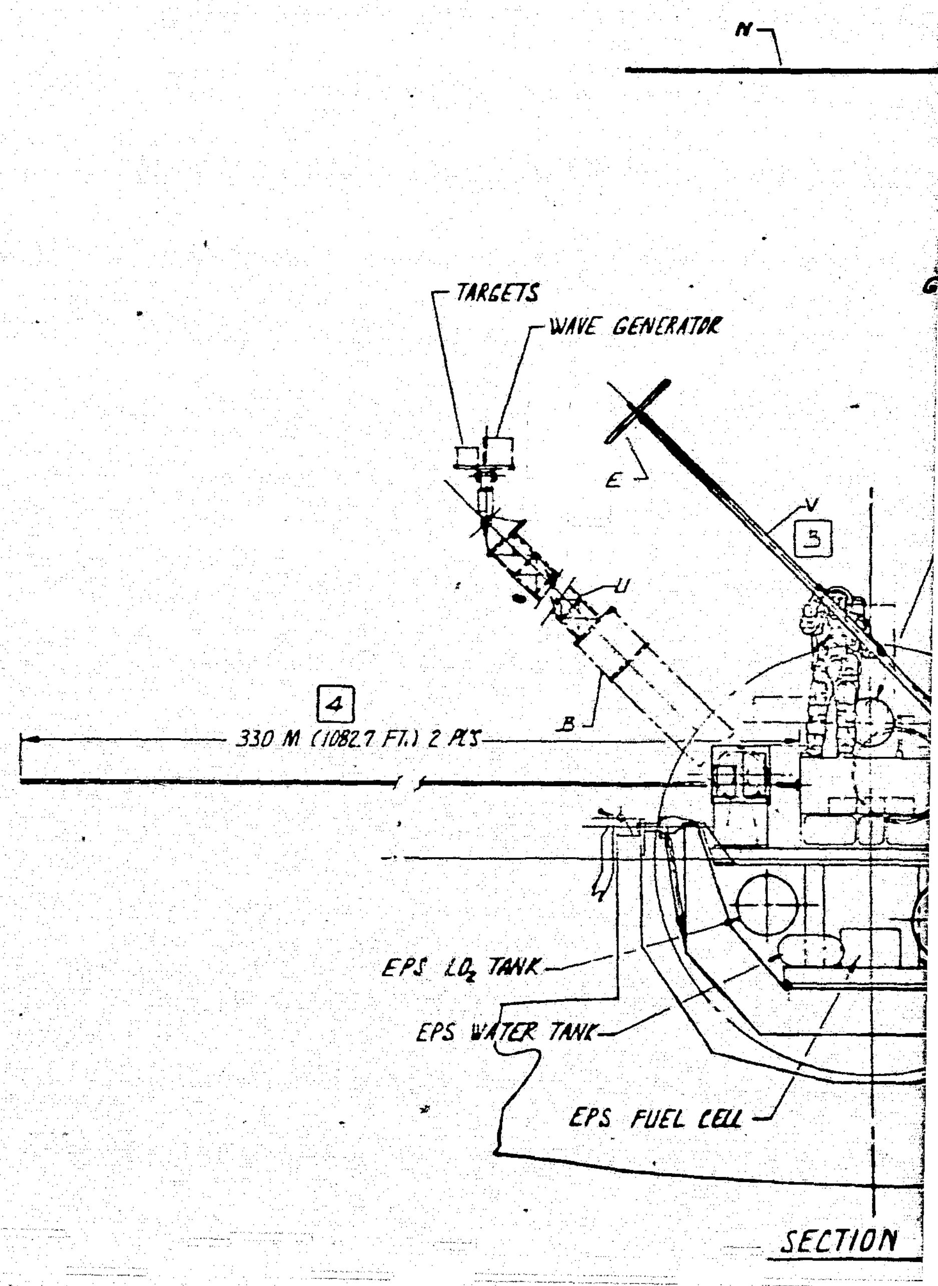
b. Laser system - Transmitter/receiver

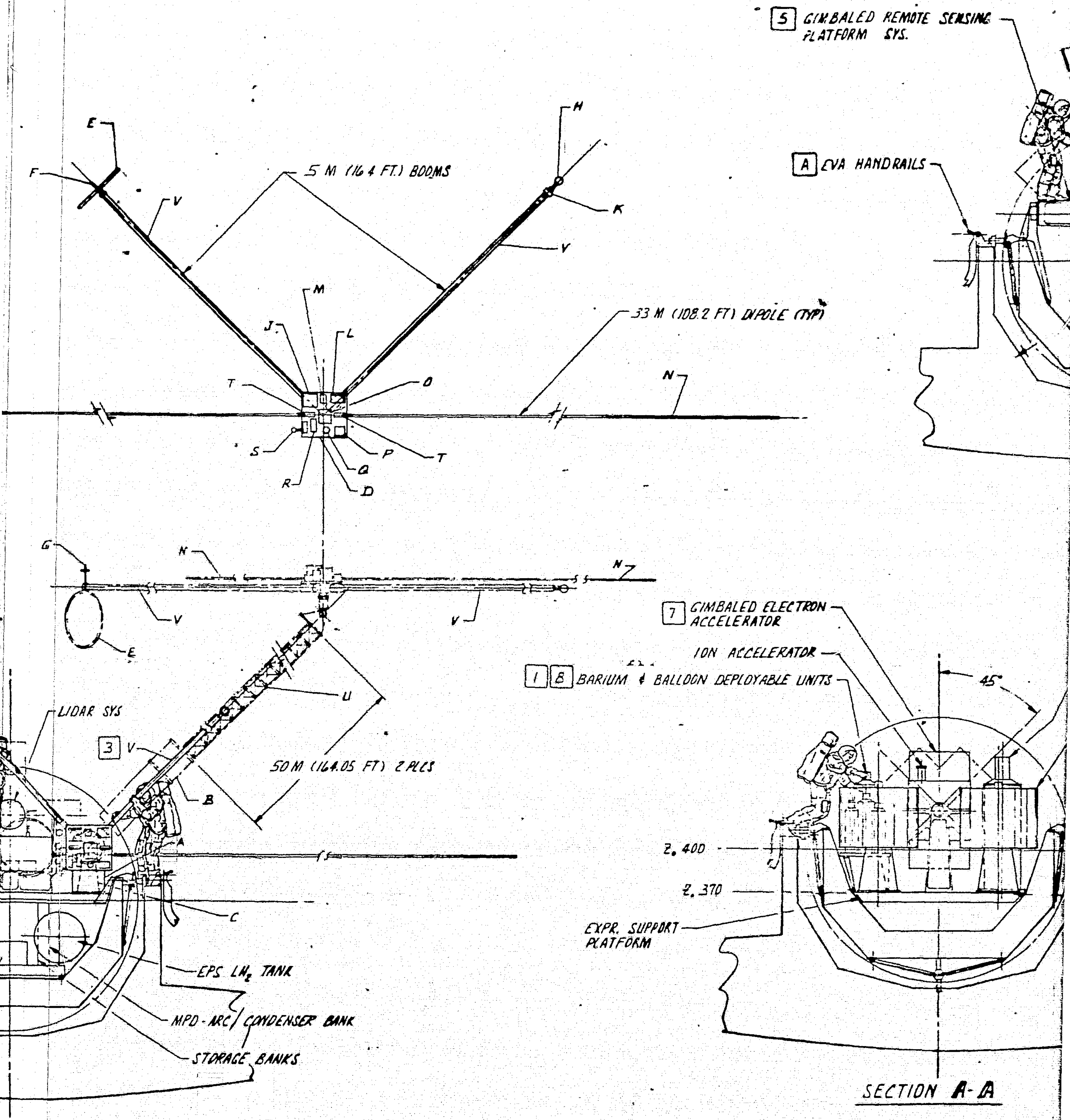
c. Transmitter coupler system - Transmitters

d. Boom system

- Magnetometers
- Power supply
- Ion probes
- Spectrometers
- Television

A MOUNTING BASE
B MAST DEPLOYMENT SYS
C LAUNCH SUPPORT STRUT
D EXPERIMENT MOUNTING PLATFORM
E 1 METER LOOP
F SHORT WAVELENGTH ELECTRIC DIPOLES
G TRIAXIAL SEARCH COILS
H RUBIDIUM MAGNETOMETER
J TRIAXIAL HEMISPHERICAL ANALYZER
K TRIAXIAL FLUXGATE MAGNETOMETER
L PLANAR ION TRAP OR NEUTRAL MASS SPECTROMETER
M ALIGNMENT TV CAMERA
N LONG ELECTRIC DIPOLE FOR AC & DC
O POWER SUPPLY & DATA SYS
P PLANAR ELECTRON TRAP
Q CYLINDRICAL PROBE
R ION MASS SPECTROMETER
S SPHERICAL ION PROBE
T STEM ACTUATOR
U DEPLOYED MAST
V 5 METER BOOMS (16.4 FT)

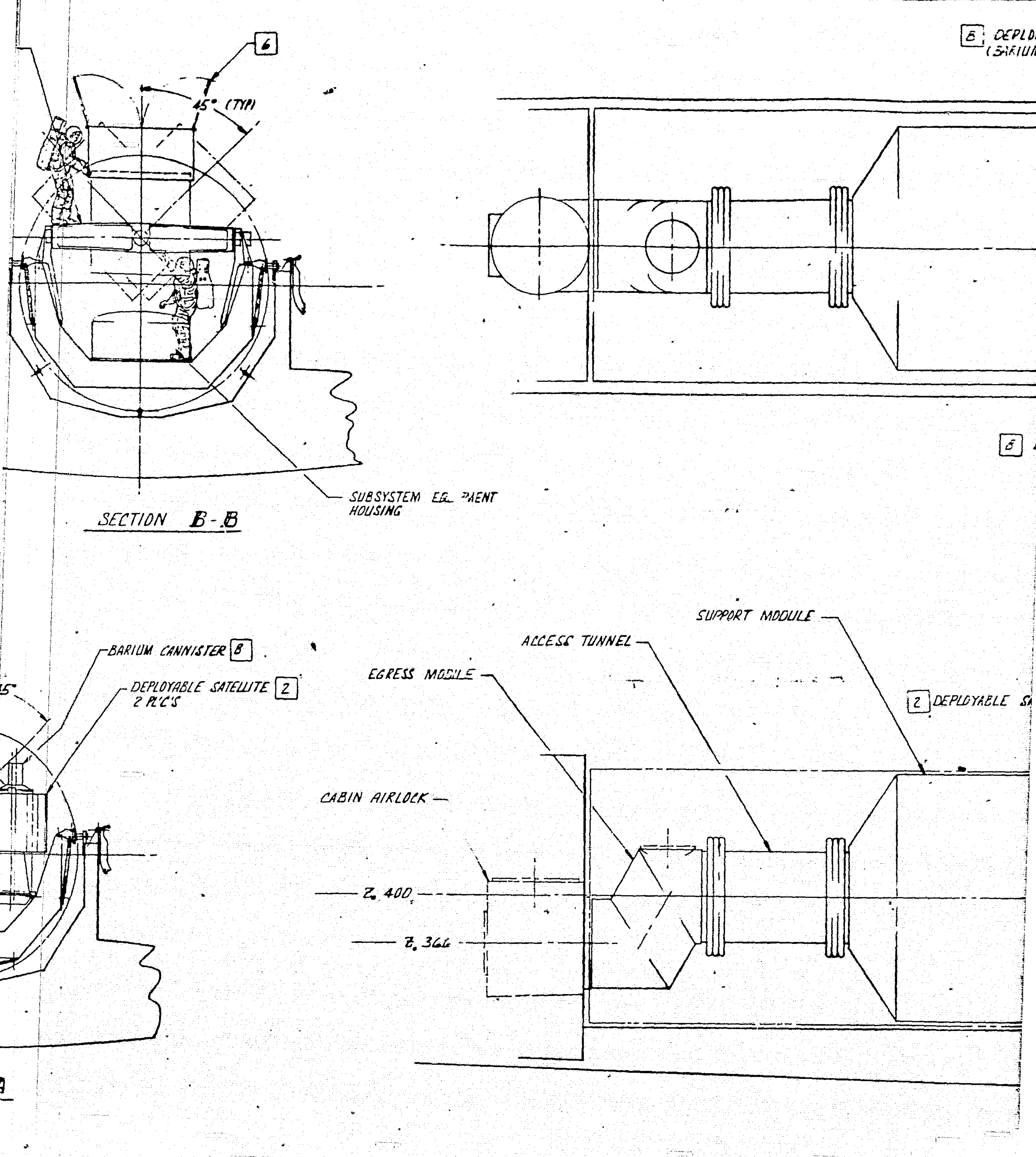


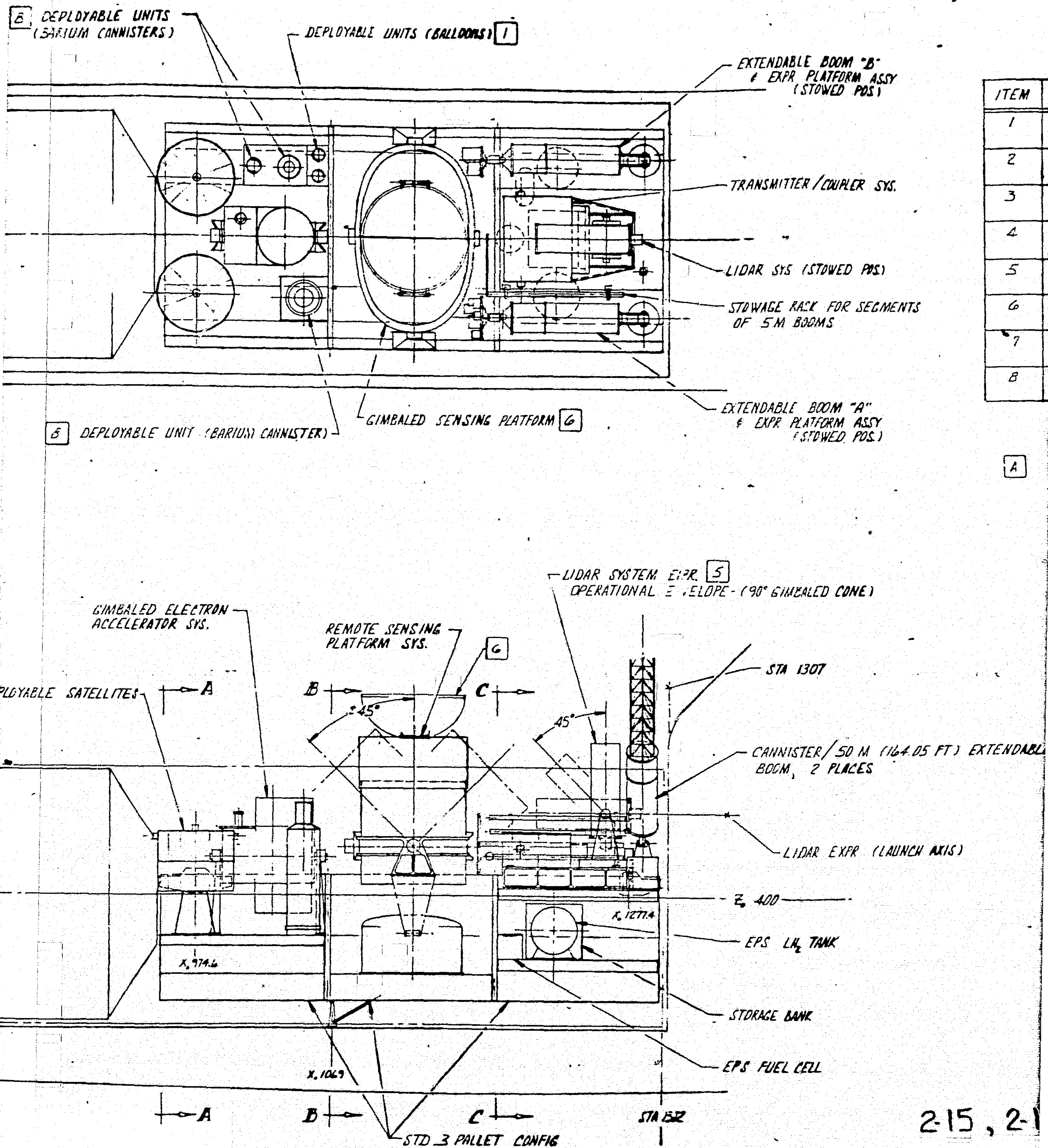


SECTION A-A

ON C-C

FOLDOUT FRAME 2


6
45° (TYP)
SUBSYSTEM
HOUSING
SECTION B-B
BARIUM CANNISTER 8
DEPLOYABLE SATELLITE 2
2 PL'C'S
SUPPORT MODULE
ACCESS TUNNEL
EGRESS MODULE
CABIN AIRLOCK
Z. 400
Z. 366
2 DEPLOYABLE



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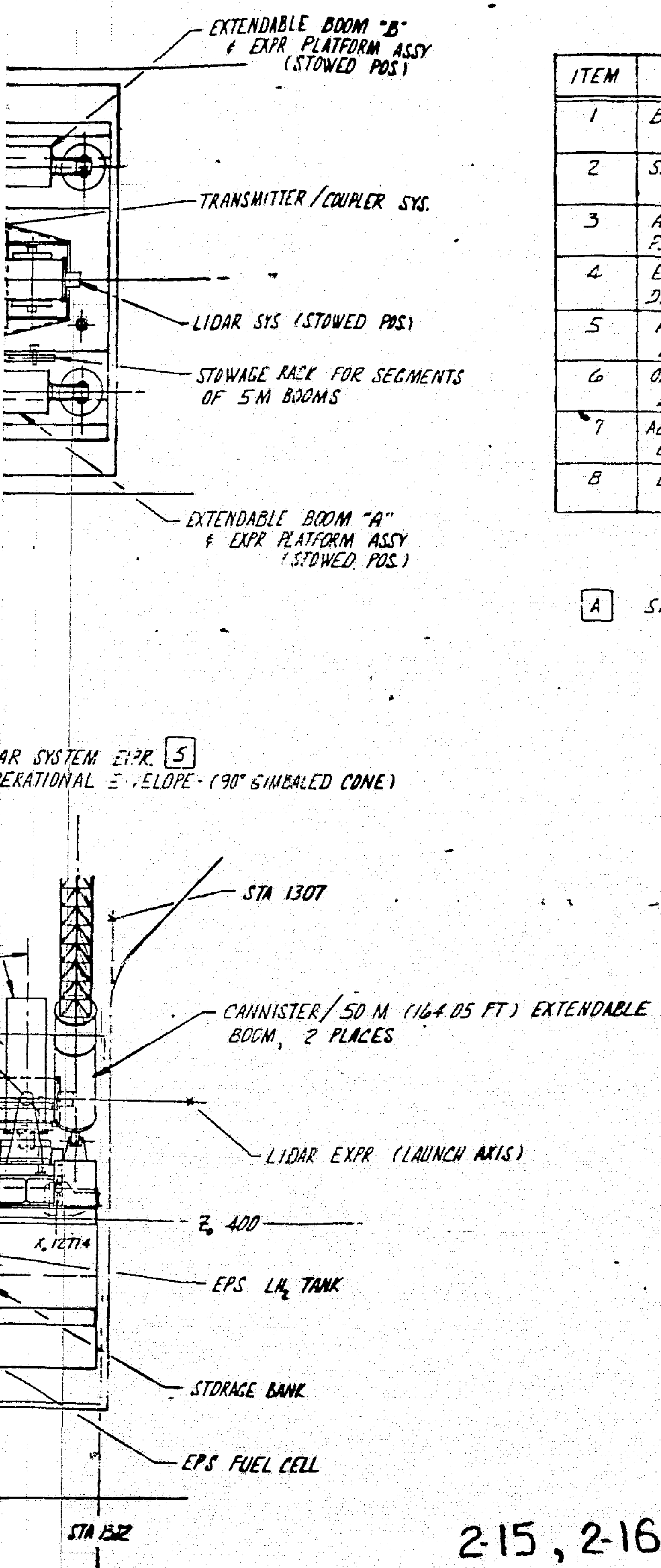


ITEM	FUNCTION	SYSTEM
1	BALLOON DEPLOYMENT	SPRING LOADED LATCHES, DETENTS & LANYARDS
2	SATELLITE DEPLOYMENT	MANUAL LATCHES, SPRING LOADED PINS SHUTTLE MANIPULATOR ARM
3	ASSEMBLY 50 M POLES/EXPR ON BOOM "A"	MANUAL ASSEMBLY, LATCHES, SPRING LOADED DETENTS
4	EXTEND 330 M DIPOLE ANTENNAS	POWER TOOL TO DRIVE EXTENSION MECHANISM
5	ACTIVATE, ERECT LIDAR EXPR	MANUAL LATCHES, DETENTS, RELEASE AUTO. GIMBAL MECHANISM
6	OPEN COVER, DEPLOY SUNSHADE RELEASE GIMBAL SYSTEM	LATCHES SPRING LOADED PINS, RELEASE AUTO. GIMBAL DRIVE MECHANISM
7	ACTIVATE ION ACCELERATOR EXPR	MANUAL LATCHES, PINS RELEASE OF EXPR POINTING DRIVE MECHANISM
8	BARIUM EXPR DEPLOYMENT	SPRING LOADED LATCHES, DETENTS, & LANYARDS

[A] SHUTTLE PROVIDED

FOLDOUT FRAME 3

SD76-SA-0026

SCALE 1/40	DATE 2-17-75	ROCKWELL INTERNATIONAL CORPORATION SPACE DIVISION 12214 LAKEWOOD BOULEVARD DOWNEY, CALIFORNIA	
ATMOSPHERIC & SPACE PLASMA PHYSICS (PHY-7) AP-06, EVA SERVICED CONCEPT EVA APPLICATIONS STUDY			4260-122

2-15, 2-16

C. Moveable/Extendable Elements

1. Boom deployments on:

   a. Boom system

      - Two each 50-m (164 ft) booms (Astromast type)
      - Two each 5-m (16 ft) booms (hollow pole masts)

2. Extendable devices

   a. Boom system

      - Two each 33-m (108 ft) dipole antenna (stem type)

   b. Transmitter/coupler system

      - Two each 330-m (1083 ft) dipole antennas (stem type)

3. Moveable devices

   a. Lidar system - contamination container

   b. Remote sensing platform

      - Contamination cover
      - Sunshade

4. Mass of device being moved and speed

   a. Remote sensing platform

      - Sunshade - 112 kg (246.4 lb) moved at 2 cm/sec (0.78 in./sec)
      - Contamination cover - 23 kg (50 lb) manual removal

   b. Lidar system

      - Transmitter/receiver and canister - 104 kg (228.8 lb) rotated 90 degrees

   c. Transmitter/coupler system

      - 330 m dipole, 16 kg (35.2 lb) moving at 1 m/6.6 sec (39.37 in./6.6 sec)

   d. Boom system

      - 50-m astromast boom assy (2 ea.), 560 kg (1232 lb) (total), moving at 2 m/60 sec (1.31 in./sec)
      - 5 m pole mast assy, 3 kg (6.6 lb), hand installed
      - 33 m dipole antenna assy, 10 kg (22 lb), moving at 1.2 m/60 sec (0.78 in./sec)

5. Accessibility

   a. Remote sensing platform - 1.9 m (dia.) (74.8 in.)

      Contains 11 instruments some of which use cryogenics and film what may require refurbishments and/or replacement. Gimbal system requires locking/unlocking. Contamination container requires stowage.

b. Lidar system

Requires depressurization, gimbal system latching/unlatching, some maintenance of optics

c. Transmitter/coupler system

Deployment of 330 m dipole antennas via handheld power unit

d. Boom system

- Assemble two 5-m boom poles and install into Boom A platform
- Unlatch Booms A and B sensor platforms
- Deploy 33 m dipole antenna. Unlatch Booms A and B boost locks

e. Deployable units - potential tasks

- Release boost latches on each unit as required
- Deploy spherical/cylindrical balloons

f. Subsatellite system

- Assist RMS mating with subsatellites for deployment
- Release boost locks
- Assist in recovery of satellites

D. Materials, Surfaces, Sensors, etc.

1. Contamination sensitive items

a. Spectrometer, XUV; UV, VIS, IR; SWIR Fourier; IR Fourier
b. Radiometer, IR
c. Interferometer
d. Photometer
e. UV-VIS camera
f. Lidar system
g. Television
h. Light source, artificial

2. Temperature characteristics

a. Non-operating temperatures at sensor:
Low = 198°K (-103°F)
High =328°K (+131°F)

b. Operating temperature at sensor:
Low = 258°K (+5.4°F)
High = 328°K (+131°F)

c. Structures range:
Low = 144°K (-200°F)
High = 422°K (+300°F)

3. Acceleration sensitivity

a. Translational acceleration

- 50 m - booms A and B
- 330 m - stem dipole antenna
- 33 m - stem dipole antenna
- 5 m - boom (pole type)
- Laser system - laser and gimbal
- Remote sensing platform gimbal

b. Rotational acceleration - see above items

c. Contact sensitivity

E. Energy Sources

1. Pyrotechnics

a. Bolt charge ignitors
b. Manual jettison alternative
c. Barium canister with explosive charges

2. AC power - 110 volts

3. DC power - Storage banks, 2-5 kilojoules, 28 volts

4. Gases - Pressurization of contamination canisters (less than 7×10^6 N/m^2, 1000 psia)

5. Cryogenics

6. RF generated energy

a. Ion accelerator
b. Electron accelerator
c. MPD-arc

7. Laser - Lidar system

8. Ionizing radiation - Gimbaled accelerator system

9. Combustables - Subsatellite system

10. Electrostatic charge - TBD

2.2.2 Space Telescope (ST)

I. PAYLOAD DESCRIPTION (Reference Drawing No. 4260-113)

A. Space Telescope (ST)

B. NASA Headquarters - AST-6; SSPD - AS-01-A

C. Astronomy

D. Spacecraft

E. 9500 kg (at launch) 9500 kg (EOL) (20,900 lb)

13 m (l) x 4.3 m (d) ascent mode (42.9 ft x 14.2 ft)

22.4 m (l) (73.9 ft) x 15.2 m (50.16 ft) (w) x 14.2 m (46.9 ft) (h) deployed mode

F. Consumables - Gas - GN_2 (purge)

G. Orbital Data - 28.5 degrees, 500 km (270 nm)

II. SUMMARY OF CANDIDATE EVA TASKS

A. Preparation for Operation and Deployment

1. Remove contamination shields from the sun sensor (1) and star trackers (2 each)

2. Unlatch boost locks for the solar panels (2) and communications antennas (2)
3. Rotate communications antennas (2) to operating position latching in place
4. Extend sunshade (1) using power tool and latch shade in extended position

B. Separate Spacecraft

1. Remove orbiter-to-spacecraft umbilicals and lock in stowed position

C. Docking Operations

1. Release RMS boost locks and secure locks
2. Engage docking latches to spacecraft
3. Unstow umbilical and connect to spacecraft
4. Unstow and engage spacecraft ground transfer mechanism

D. Planned Maintenance

1. Unstow and replace contamination shields on sun sensor (1) and star tracker (2)
2. Open spacecraft access, remove failed component, translate to spares storage
3. Open spares storage. Release restraints. Removes spares equipment and replace failed unit and secure
4. Replace new unit and secure access panel(s)
5. Service fluid system by releasing tank retention latches. Break disconnect. Remove tank to storage. Transfer new tank. Secure and reconnect

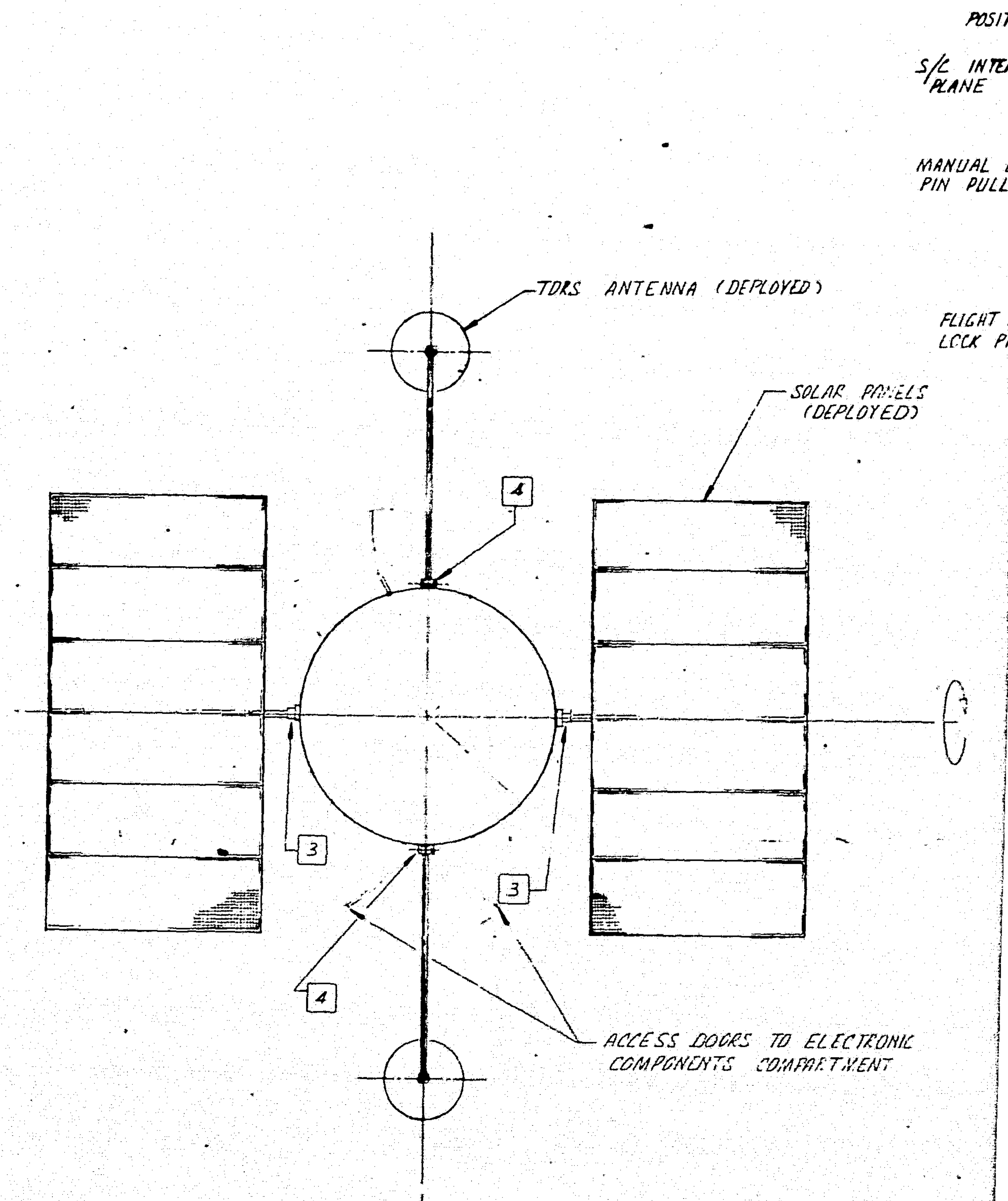
E. Prepare for Return

1. Basically a reverse process of II.A and II.C

III. EVALUATION OF EVA INTERFACES

A. Structure

1. Twist, pull and push latches, boost locks, spares storage and spacecraft panel latches
2. Handholds near each latch and/or lock in excess of 0.6 m (24 in.). Foot restraints required when handholds cannot be accommodated or when both hands are required to perform task (i.e., spares retrieval/failed module stowage)
3. Handholds must support a push/pull torque of 34 N-m (300 in.-lb) and foot restraints 170 N-m (1500 in.-lb)
4. "Clothes line" type spares transfer system for module replacement



SECTION B-B

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OF POOR QUALITY

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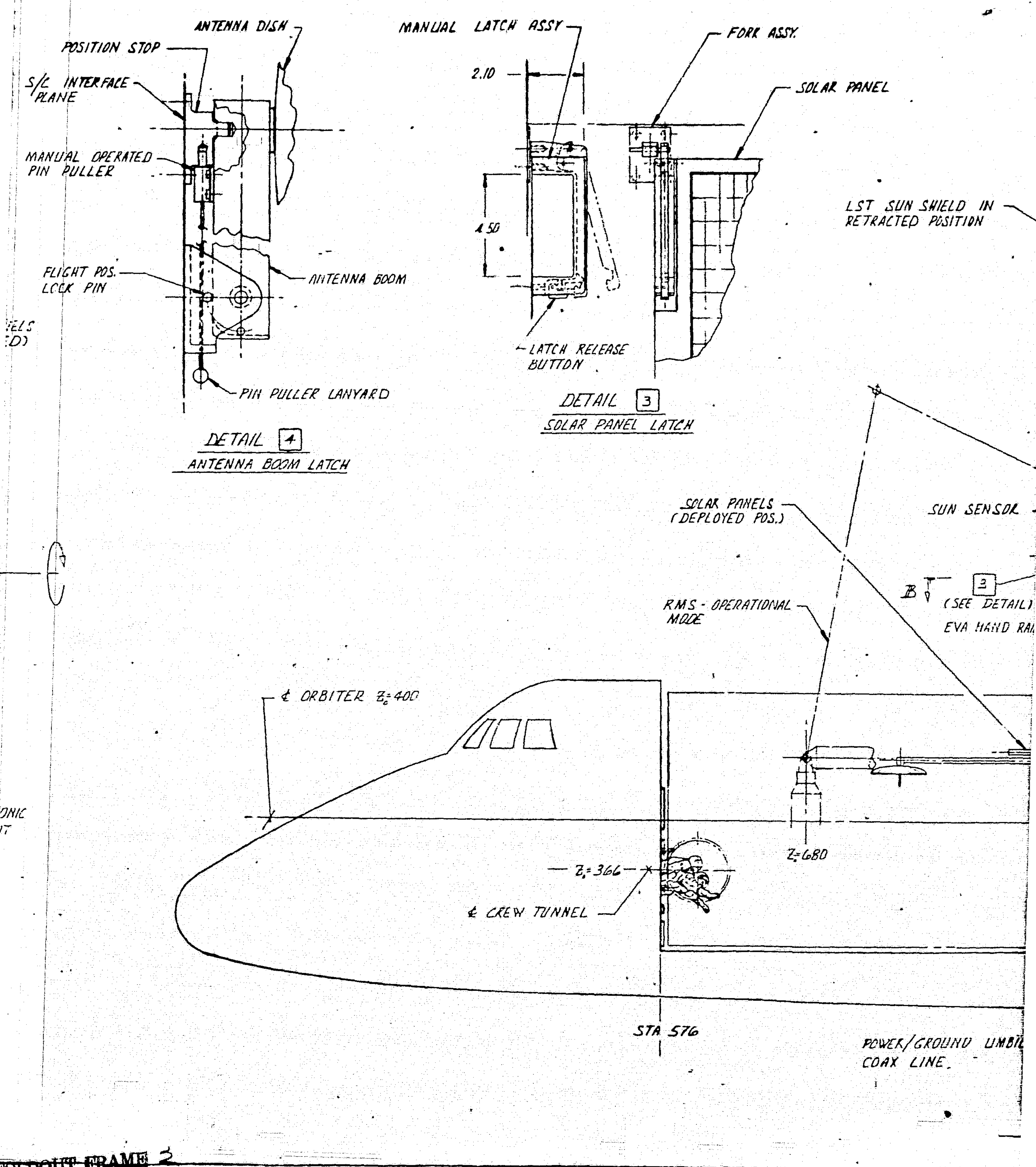
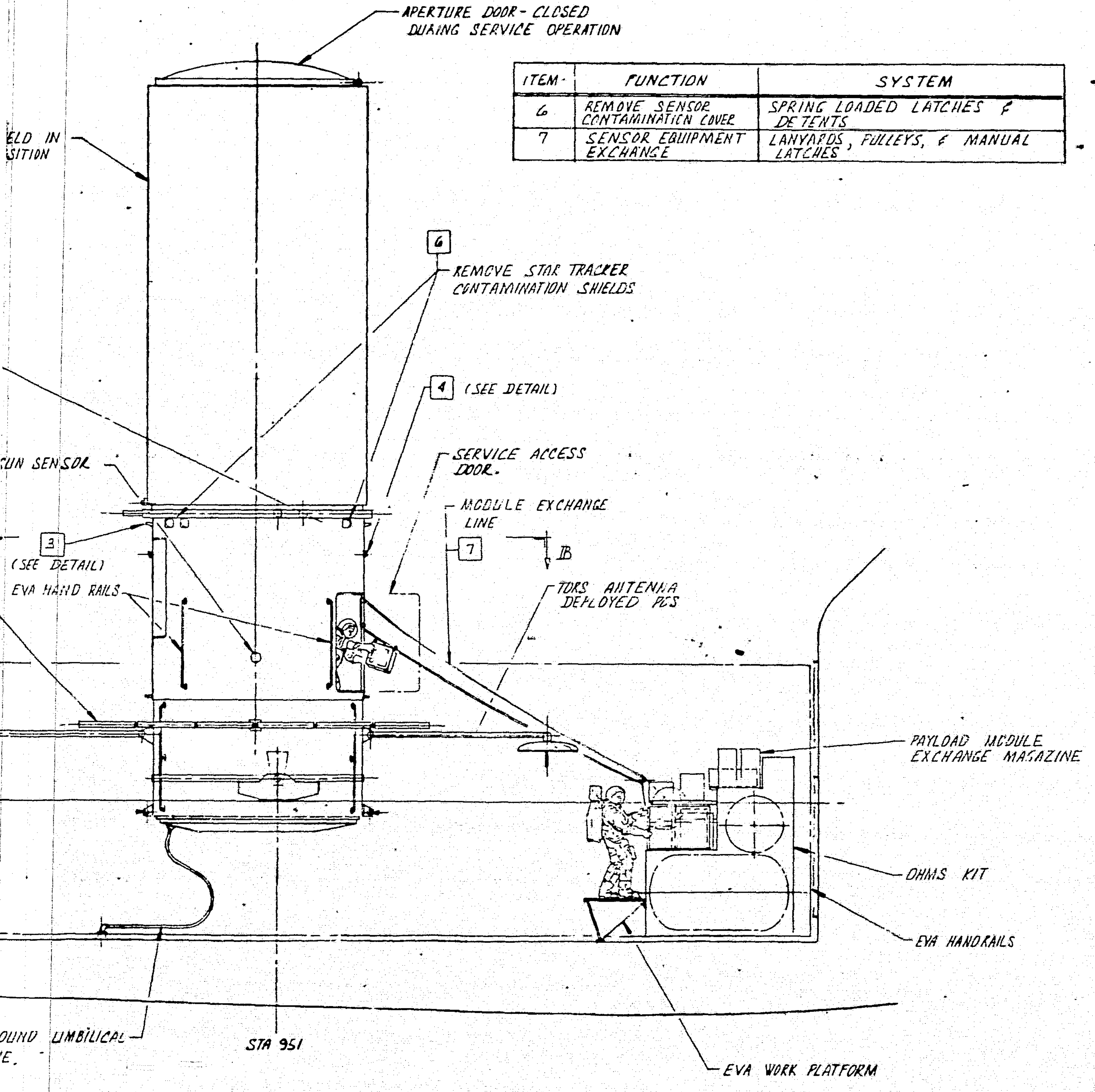


FOLDOUT FRAME 2

ITEM	FUNCTION	SYSTEM
6	REMOVE SENSOR CONTAMINATION COVER	SPRING LOADED LATCHES & DETENTS
7	SENSOR EQUIPMENT EXCHANGE	LANYARDS, PULLEYS, & MANUAL LATCHES



LST - SERVICE MODE

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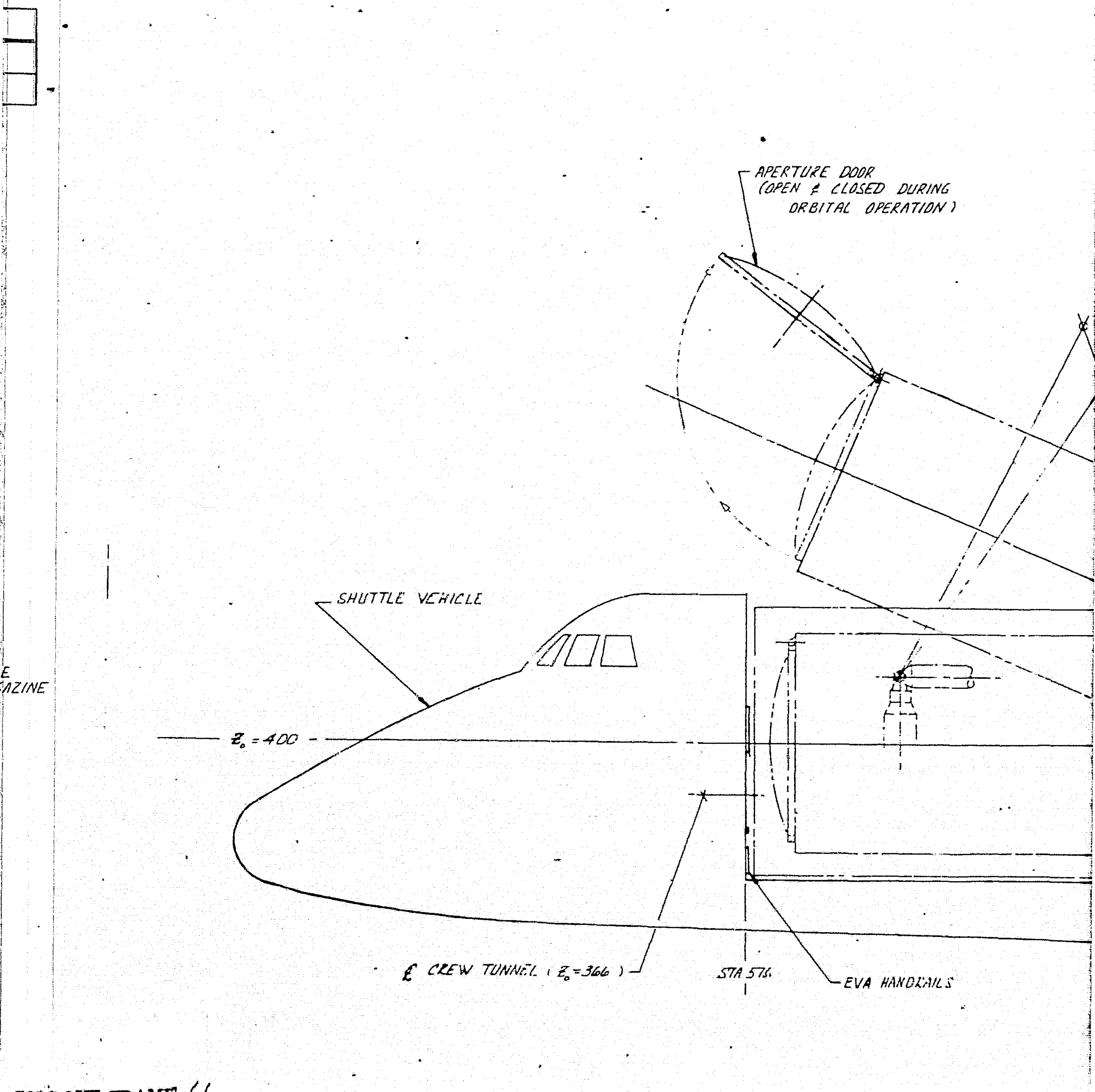
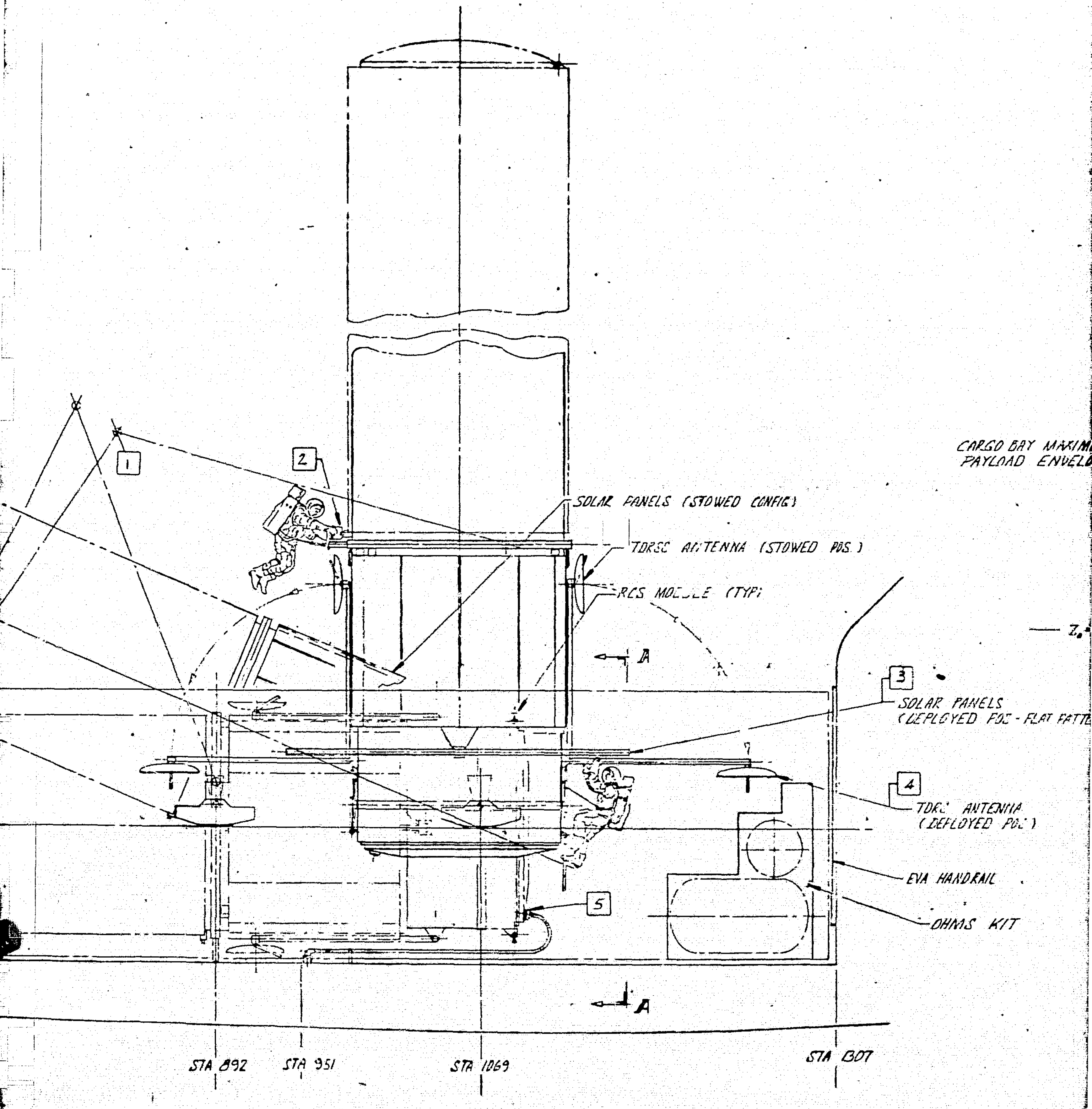


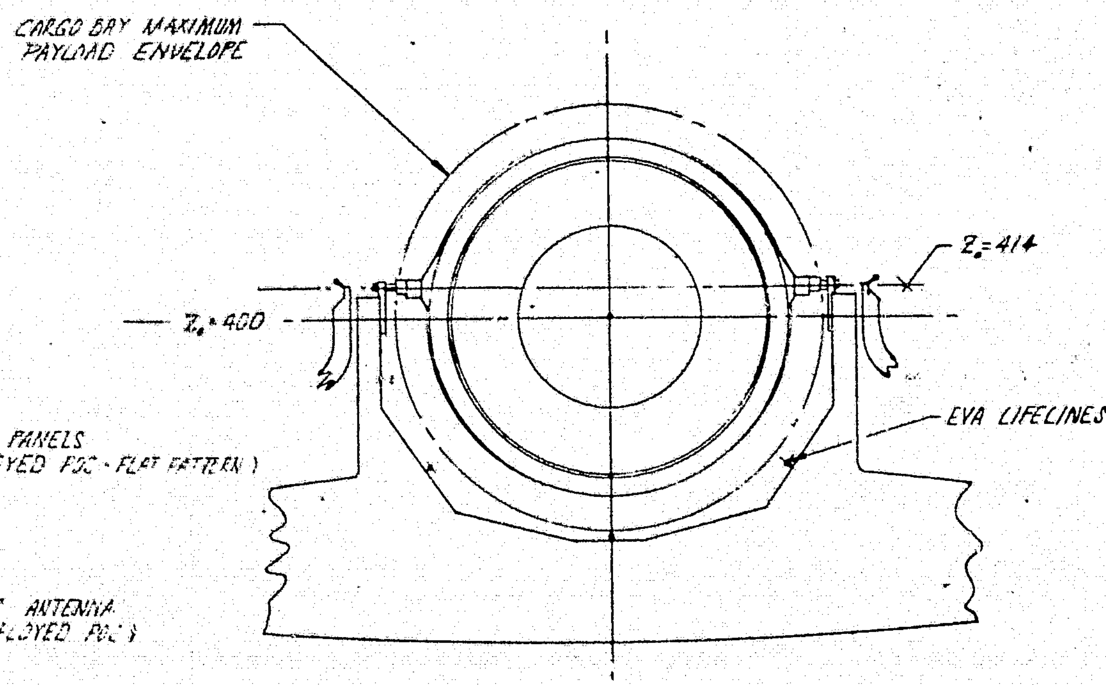
FOLDOUT FRAME 4



LST - PRE LAUNCH MODE

FOLDOUT FRAME 5

ITEM	FUNCTION	SYSTEM
1	ELEVATE LST TO VERTICLE POSITION	SHUTTLE MANIPULATOR ARM
2	SUN SHADE EXTENSION	POWER TOOL TO DRIVE EXTENSION MECHANISM
3	DEPLOY SOLAR ARRAY PANELS	MANUAL LATCHES, SPRING LOADED DETENTS
4	DEPLOY TDRS ANTENNAS	LANYARDS, SPRING LOADED LATCHES & DETENTS
5	DISCONNECT POWER SIGNAL & GND. UMBIL.	MANUAL ACTUATED CONNECTORS



SECTION A A

3 SOLAR PANELS (DEPLOYED POS - FLAT PATTERN)

4 TDRS ANTENNA (DEPLOYED POS)

EVA HANDRAIL

OHMS KIT

FOLDOUT FRAME 6

SD 76-SA-0026

2-21, 2-22

SCALE 1/40	ROCKWELL INTERNATIONAL CORPORATION SPACE DIVISION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA
LARGE SPACE TELESCOPE (AST-6) AS-01, EVA SERVICED CONCEPT EVA APPLICATIONS STUDY	4260-113

5. Work platforms on pallet and on spacecraft plus mobility aids in support of maintenance activity

6. Access hatches on spares container and spacecraft

7. Most modules weigh 16 (35.2 lb) to 78 kg (171.6 lb) (majority 23-43 kg (50.6-94.6 lb))

B. Removable Modules (Maintenance)

1. Remove/replace equipment boxes from

   a. Spacecraft subsystems
   b. Spacecraft experiment equipment

C. Movable/Extendable Elements

1. Elements

   a. Sunshade, right circular cylinder; 320 kg (704 lb)
   b. TDRS antennas; 2 ea. 4.54 m (15 ft) Astromasts; 10 kg (22 lb)
   c. Solar array; 33.5 m^2; 185 kg (364.8 ft^2; 407 kg)
   d. Sensor optic covers; multiple shapes and weights

2. Time criticality - None identified; Potential loss of GN_2

D. Materials, Surfaces, Sensors

1. Contamination sensitive items

   a. Telescope lenses
   b. Sun sensor
   c. Star trackers

2. Temperature characteristics/data

   Internal temperature 294 $\pm$ 2°K (70 $\pm$ 2°F)

   a. Telescope interior - optically black
   b. Sunshade and telescope barrel - solar reflector coating
   c. SIP section - bare aluminum interior, ML1 exterior
   d. SSM section - bare aluminum interior, ML1 or ML1 coating. White radiator areas. Base - anodized aluminum/black CAT-A-LAC coating. Interior - high emittance satin finish, light color

3. Acceleration sensitivity (g) - None identified

4. Contact sensitivity
   MLI - can be damage
   Solar panels - easily broken

E. Energy Sources (1975 SSPD)

1. Pyrotechnics - None indicated

2. AC power - None required

3. DC power - 2200 W peak
   1500 W avg (50.4 kwhr)
   28 vdc

2.2.3 LANDSAT/MMS

I. PAYLOAD DESCRIPTION (Reference Drawing No. 4260-111)

A. LANDSAT

B. NASA Headquarters - EO-3; SSPD - EO-8-A

C. Earth Observations - GSFC

D. Spacecraft (with built-in velocity package)

E. 3475 kg (7645 lb) (at launch); 2953 kg (6497 lb) (EOL)

3.05 m (10.1 ft) (w) x 2.8 m (9.2 ft) (d) x 11.0 m (36.3 ft) (h) - ascent mode

6.53 m (21.5 ft) (w) x 2.8 m (9.2 ft) (d) x 11.0 m (36.3 ft) (h) - deployed mode

F. Consumables

1. Gas - cold gas
2. Propellant - hydrazine. Solid engine (SVM-2 rocket)

II. SUMMARY OF CANDIDATE EVA TASKS

A. Preparation for Operations and Deployment

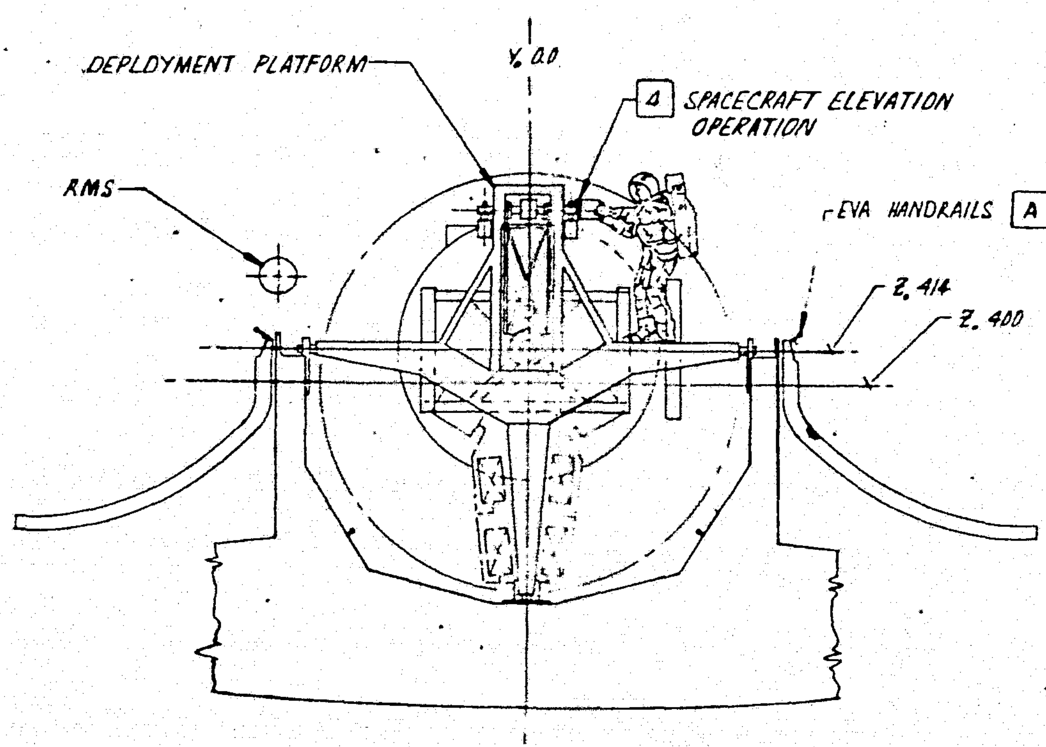
1. Remove contamination shields from all spacecraft subsystem optics and scientific sensors
2. Unlock boost latches for solar panel. Unfold and lock solar panel sections in open position
3. Release boost locks on docking platform and rotate platform and MMS to vertical
4. Assist RMS attachment; release platform/MMS retention devices
5. Remove spacecraft umbilical and stow

B. Docking Operations

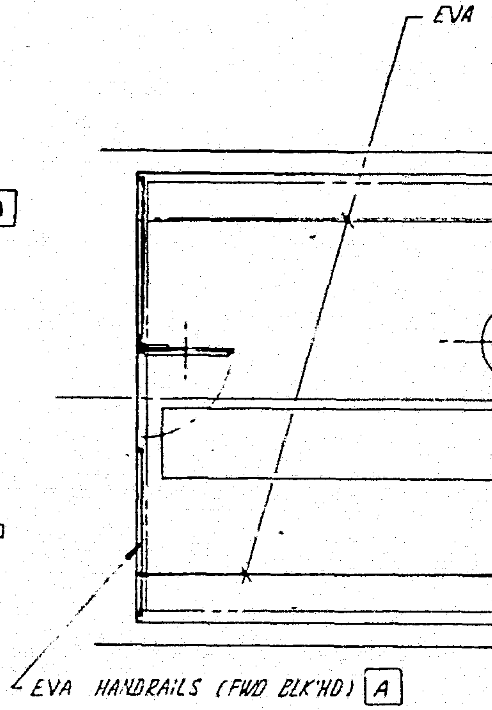
1. Release boost locks in preparation for docking
2. Manually assist payload positioning to docking ring
3. Operate docking latches
4. Retrieve umbilical and connect to payload

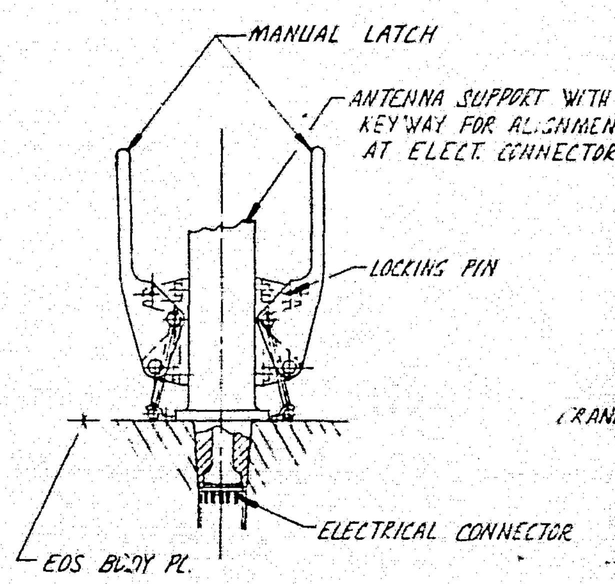
C. Planned Maintenance

1. Replace sensor covers
2. Remove spacecraft covers and stow
3. Safety spacecraft phyrotechnics
4. Remove storage covers and spares restraints
5. Perform equipment/spares exchange for unique mission equipment
6. Clean equipment as required



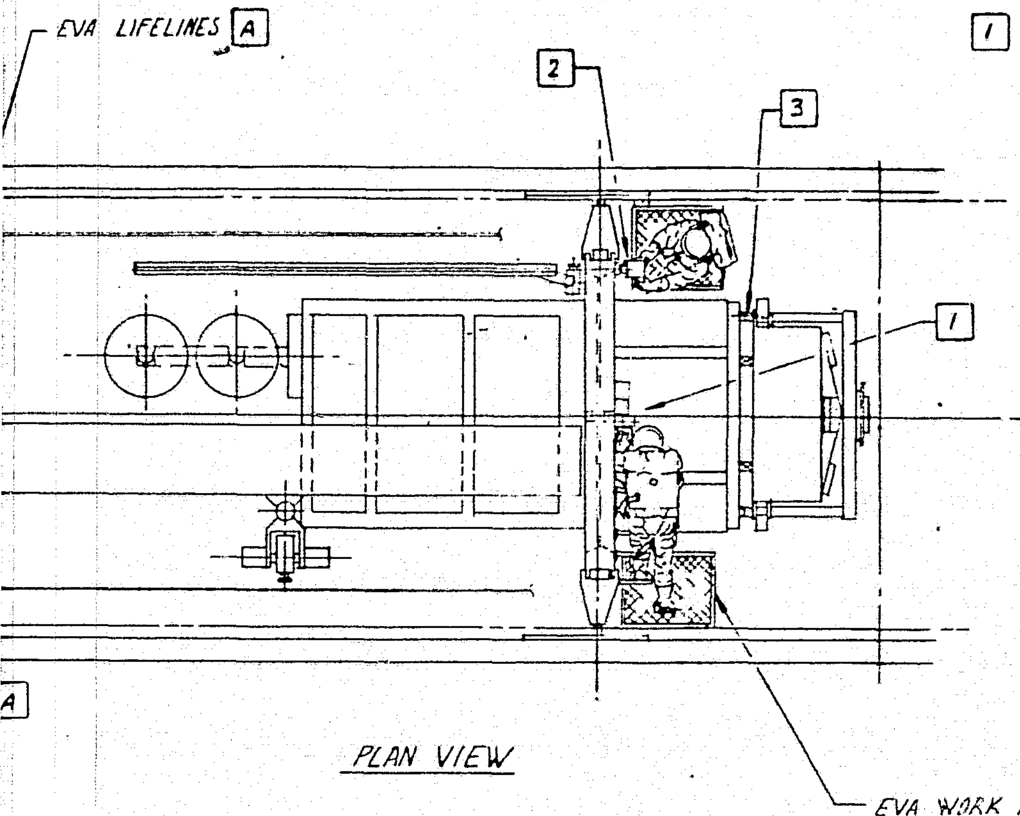
SECTION B-B



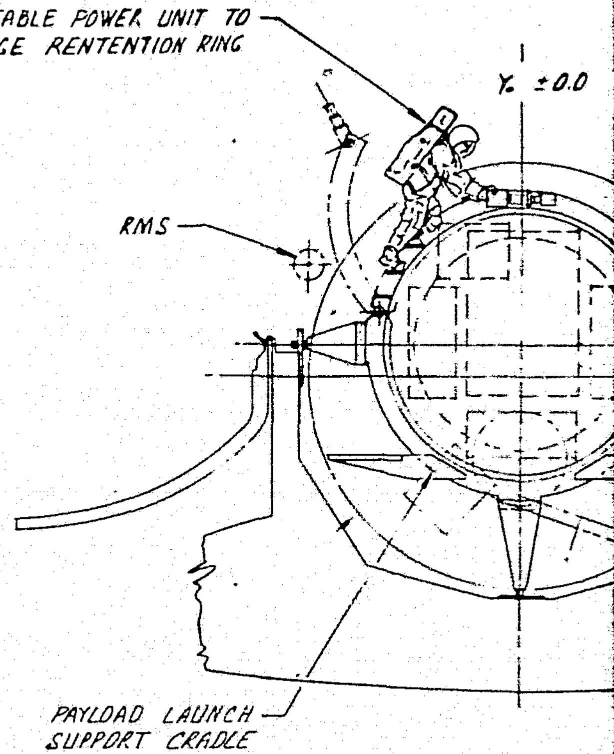


DETAIL 6 MECHANISM

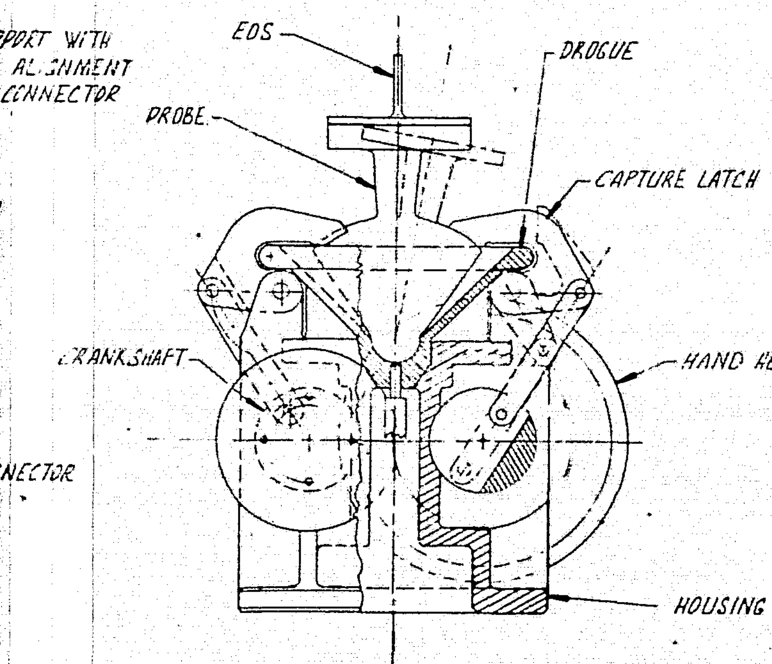
SCALE 1/4 SIZE



PLAN VIEW

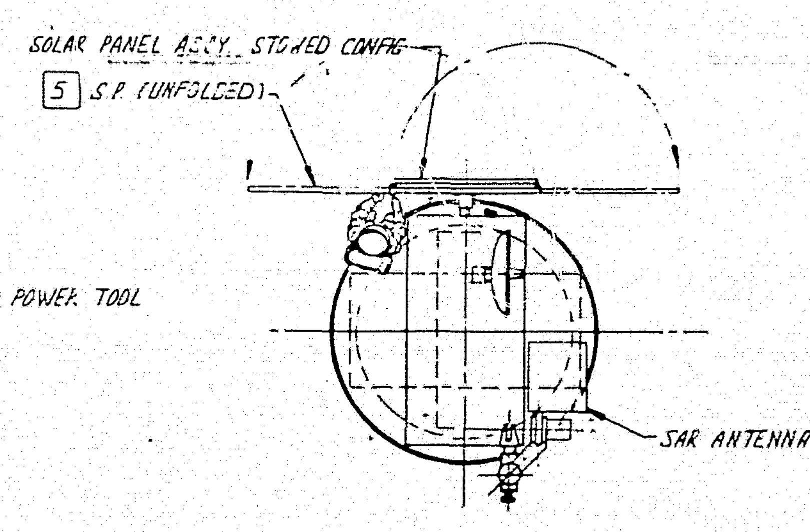


SECTION A



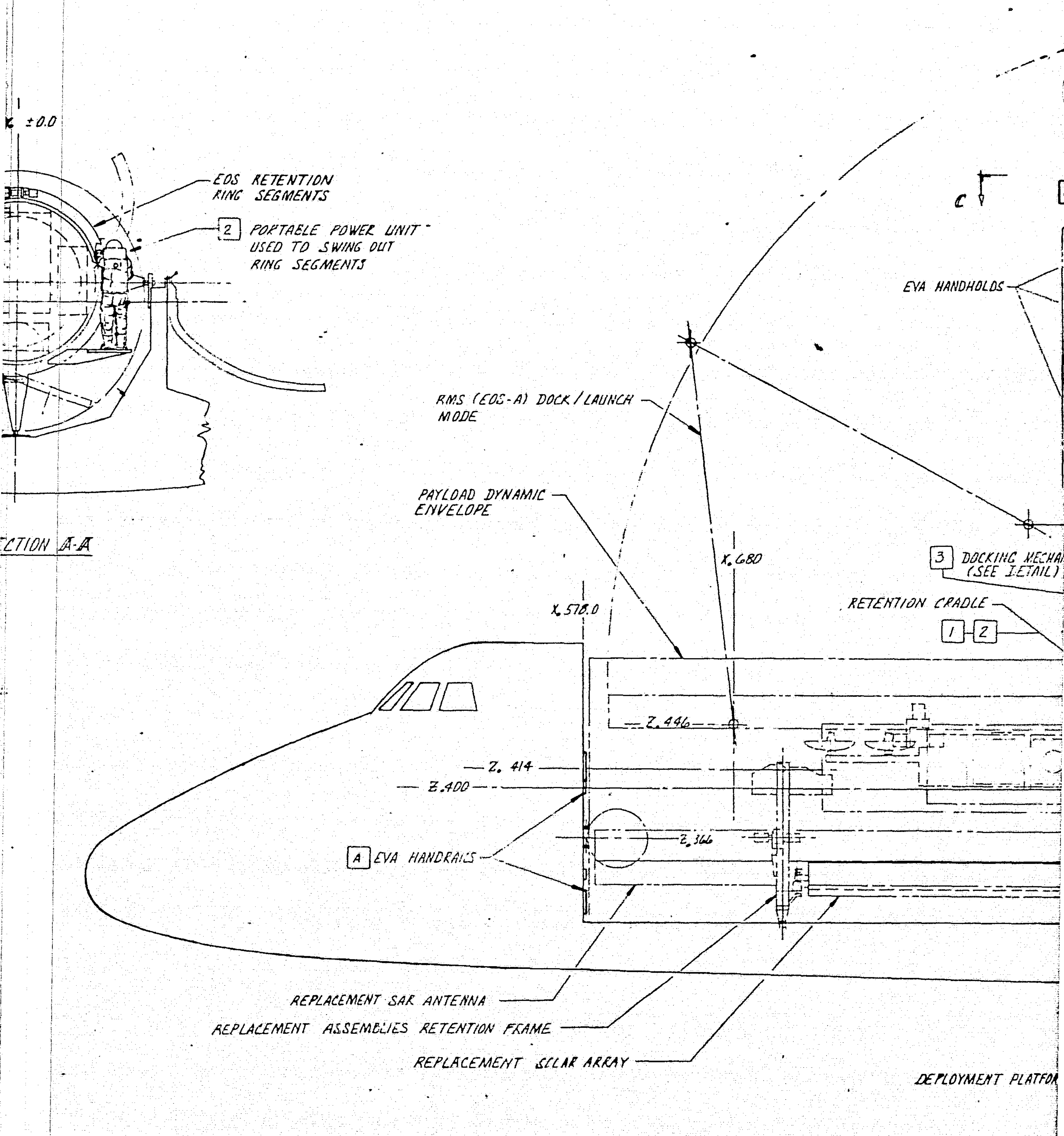
DETAIL 3 DOCKING MECHANISM

SCALE: HALF

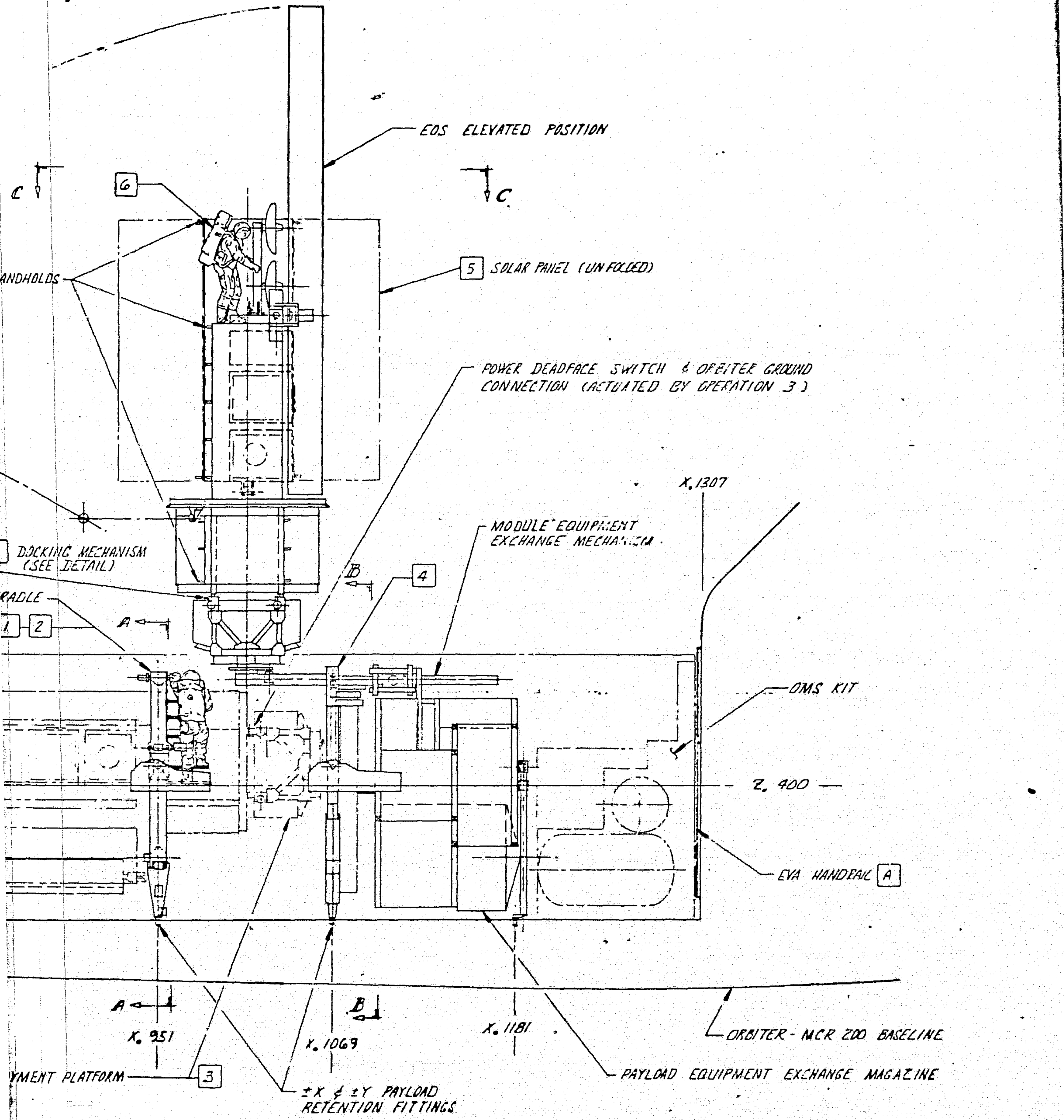


VIEW C-C

FOLDOUT FRAME 2



FOLDOUT FRAME 3



FOLDOUT FRAME 4

ITEM	FUNCTION	SYSTEM
1	DISENGAGE BOLT LATCHES ON RETENTION CRADLE SEGMENTS	POWER TOOL ACTUATION OF LATCHES
2	RETRACT RETENTION CRADLE ASSEMBLYS	POWER TOOL DEPLOYMENT OF SEGMENTS
3	DOCKING OF SPACE-CRAFT TO DEPLOYMENT CAGE	POWER TOOL OPERATION OF BERTHING LATCHES
4	DEPLOY PAYLOAD	POWER TOOL OPERATION OF DEPLOYMENT PLATFORM
5	UNFOLD SOLAR PANEL AND RE-SECURE	MANUAL OVER CENTER LATCHES & SPRING LOADED DETENTS
6	ANTENNA REPLACEMENT EXCHANGE	MANUAL OVER CENTER LATCHES

[A] SHUTTLE PROVIDED

IND
?)

OMS KIT

OO —

/A HANDRAIL [A]

- MCR 200 BASELINE

EXCHANGE MAGAZINE

FOLDOUT FRAME 5

SD 76-SA-0026

2-25, 2-26

SCALE 1/40	DR / DATE / MODEL	ROCKWELL INTERNATIONAL CORPORATION SPACE DIVISION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA	
EARTH OBSERVATORY SATELLITE (EO-3), EO-C8 — EVA SERVICED CONCEPT, EVA APPLICATIONS STUDY			4260-111

D. Prepare for Return

1. Perform operations under II.B.1 through 4
2. Replace protective shields (II.A.1)
3. Engage entry latches on solar panel and antennas (II.A.2)
4. Perform following steps in reverse manner:
   a. Step II.A.4
   b. Step II.A.3

III. EVALUATION OF EVA INTERFACES

A. Structures

1. Twist, push and pull of latches and boost locks
2. Handhold near each latch and/or lock in excess of 0.6 m (24 in.) Foot restraints required when handholds cannot be accommodated.
3. Handholds must support a push/pull torque of 34 N-m (300 in.-lb) and foot restraints 170 N-m (1500 in.-lb)
4. Personnel belt restraints required during equipment exchange ($\sim$250 kg (550 lb))
5. Removal of contamination covers and stowage. Range of covers 0.6 m (2 ft) to approximately 0.15 m (0.5 ft)
6. Astronaut body access between equipment
7. Work platforms with foot restraints and belt restraints mounted on spacecraft

B. Removable Modules (Maintenance)

1. Remove/replace electronic boxes from
   a. Attitude control system
   b. Power module
   c. Orbit adjust package
2. Remove/replace scientific equipment packages
   a. Communications
   b. Synthetic aperture radar atenna

C. Movable/Extendable Devices

1. Positioning platform capture latches
   a. Mass - 2 kg (4.4 lb) 4 required
   b. Torque - 3 N-m (24 in.-lb)
2. Positioning platform rotation mechanism
   a. Mass - 4 kg (8.8 lb), 1 required
   b. Torque - 20 N-m (180 in.-lb)

D. Materials, Surfaces, Sensors

1. Contamination sensitive items
   a. Thematic mapper

b. High resolution imager
c. Pollution monitoring system

2. Temperature characteristics

a. Non-operating temperatures
(1) Sensors: 248°K (-13°F) to 398°K (257°F)
(2) General structure: 58°K (-354°F) to 398°K (257°F)

b. Operating temperatures
(1) Sensors: 258°K (5.4°F) to 323°K (121°F)
(2) Spacecraft subsystems: 278°K (41°F) to 328°K (131°F)

3. Acceleration sensitivity (g)

a. Translation - 3.5 g max
b. Rotation - 0.1 degree/sec^2

4. Contact sensitivity

a. Solar panels
b. SAR antenna
c. Sensor lenses

E. Energy Sources

1. Pyrotechnics

a. Bolt charge ignitor (shorting plug)

2. AC power - none required

3. DC power - 28 vdc

4. Gases - propellants

Pressurant for propulsive motors
Hydrazine replacement

5. Cryogenics - none

6. Combustables

a. Hydrazine
b. Solid state motor (SVM-2)

2.2.4 Astronomy Spacelab Payload (ASP)

I. DESCRIPTION (Reference Drawing No. 2617-1)

A. Astronomy Spacelab Payloads (ASP)

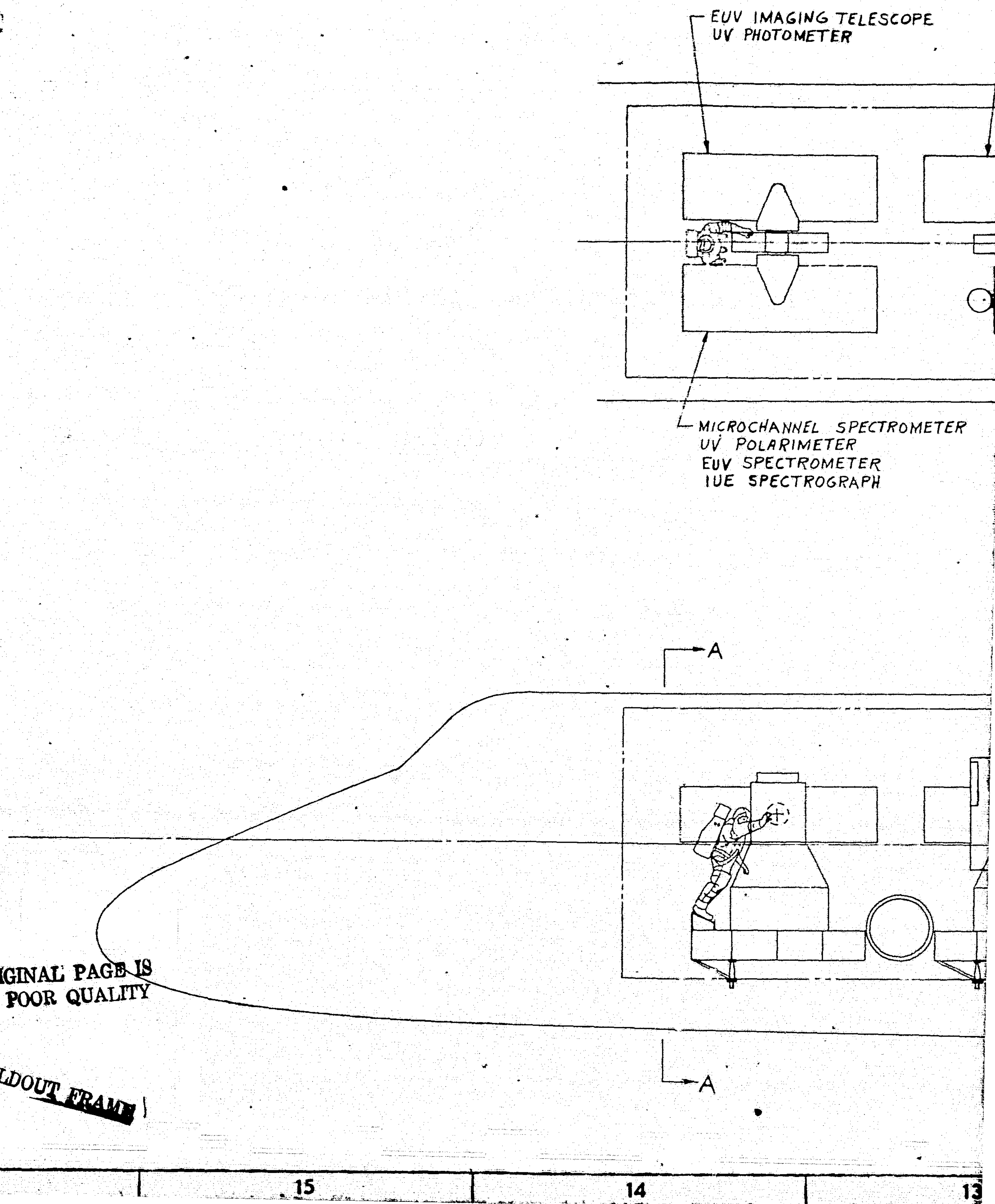
B. NASA P/L AST-10 (similar to elements of SSPD AS-04, 41, 66)

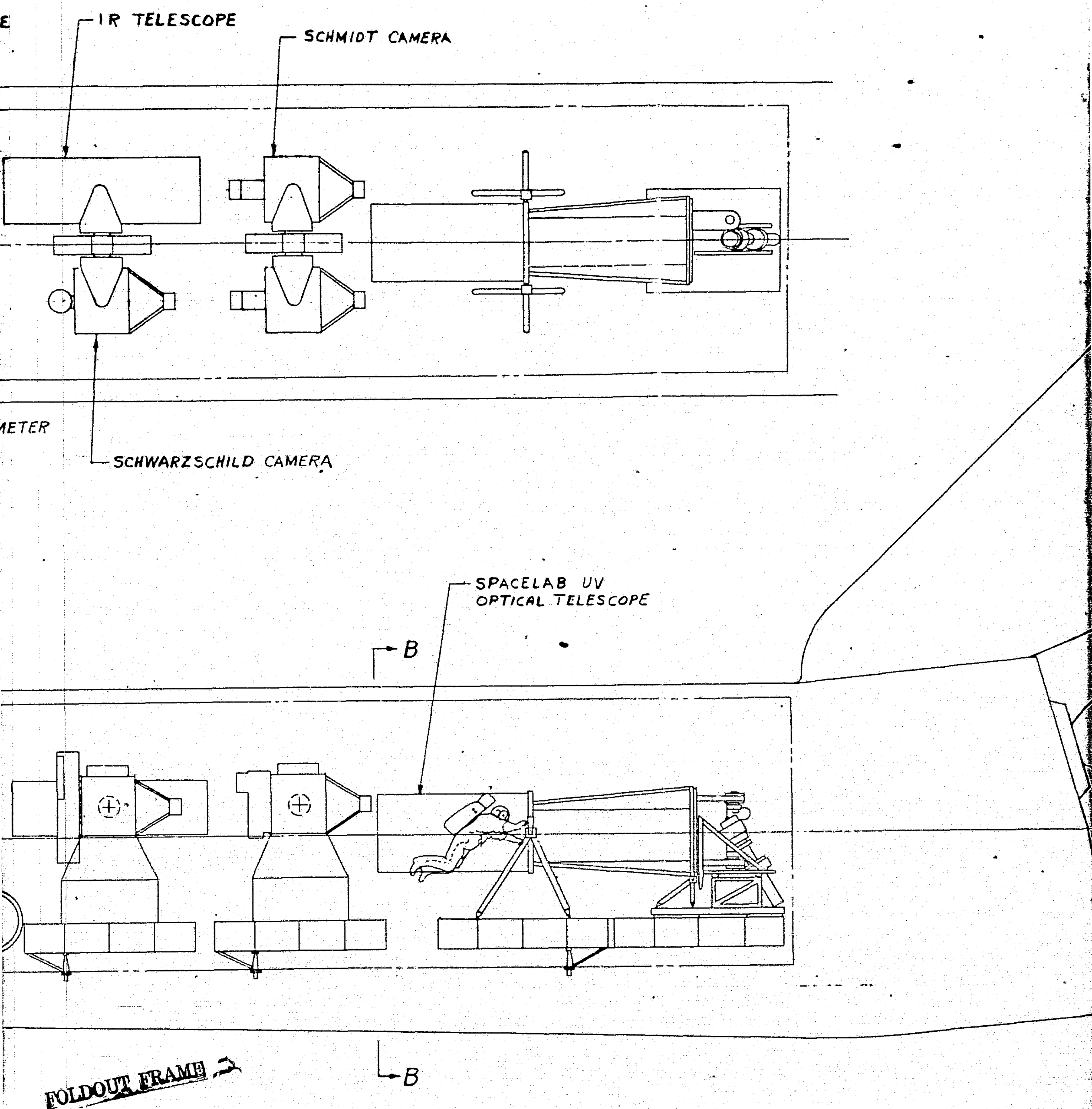
C. UV-Stellar Astronomy - GSFC

D. Spacelab Pallet

E. 14,507 kg (31,915 lb), 15 m (49.5 ft) length x 4.5 m (14.8 ft) dia.

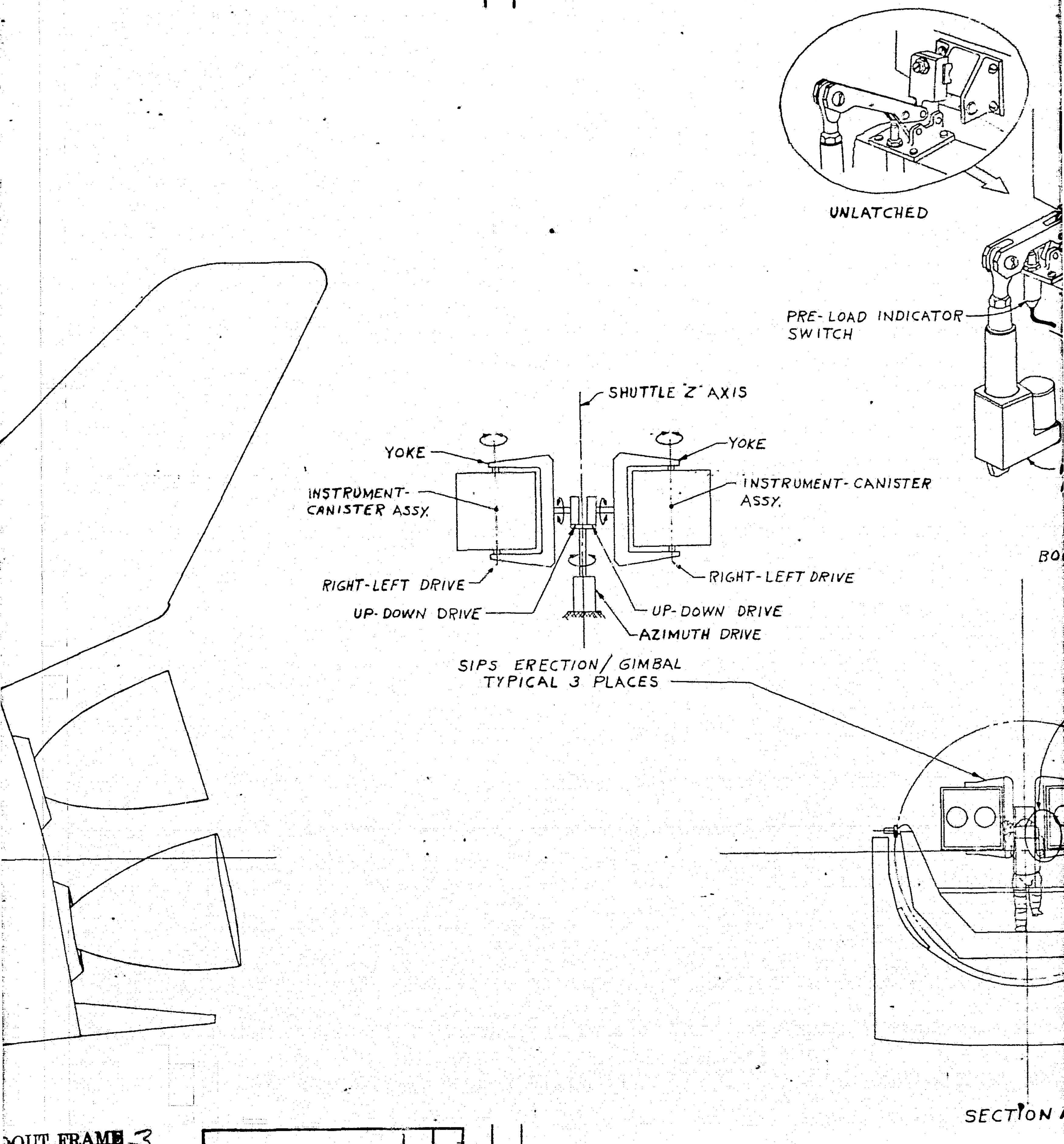
F. Film, cryogenics, and helium


EUV IMAGING TELESCOPE
UV PHOTOMETER
MICROCHANNEL SPECTROMETER
UV POLARIMETER
EUV SPECTROMETER
IUE SPECTROGRAPH
A
A
16
15
14
13



FOLDOUT FRAME

13	12	11	10



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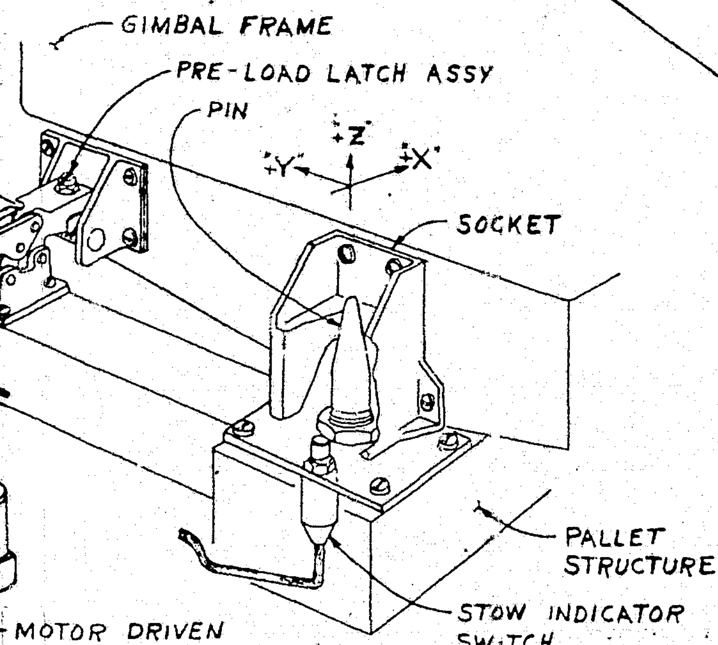
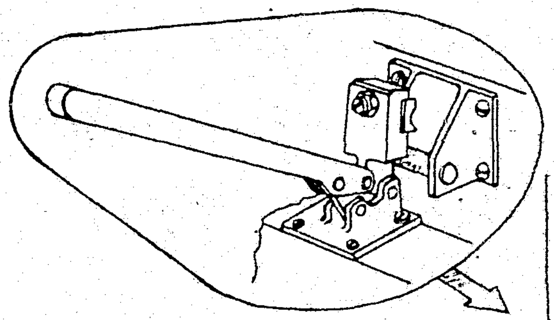
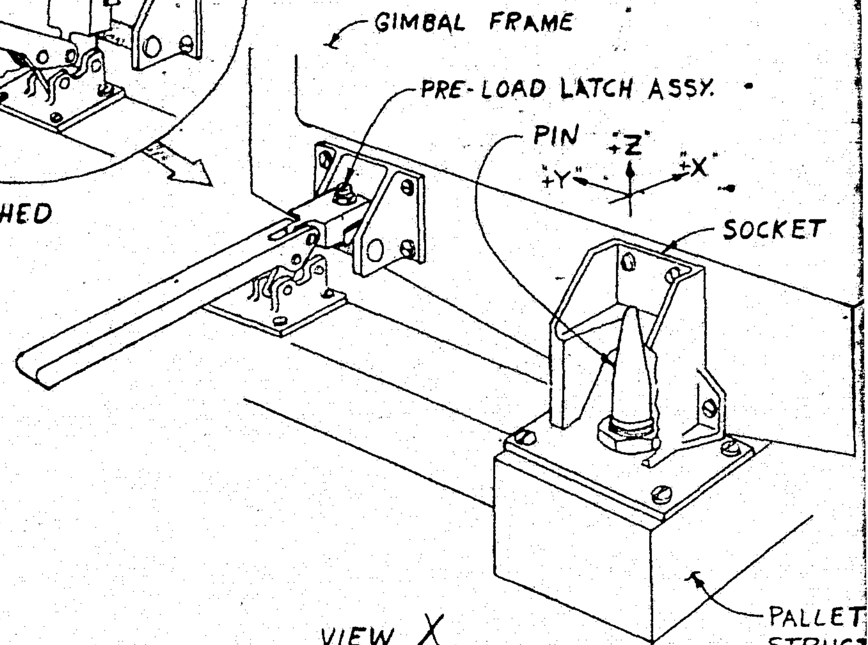


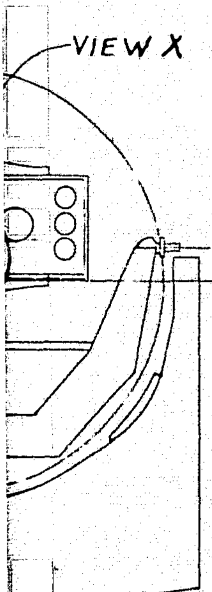
VIEW X
AUTOMATED VERSION
BOOST LATCH MECHANISM



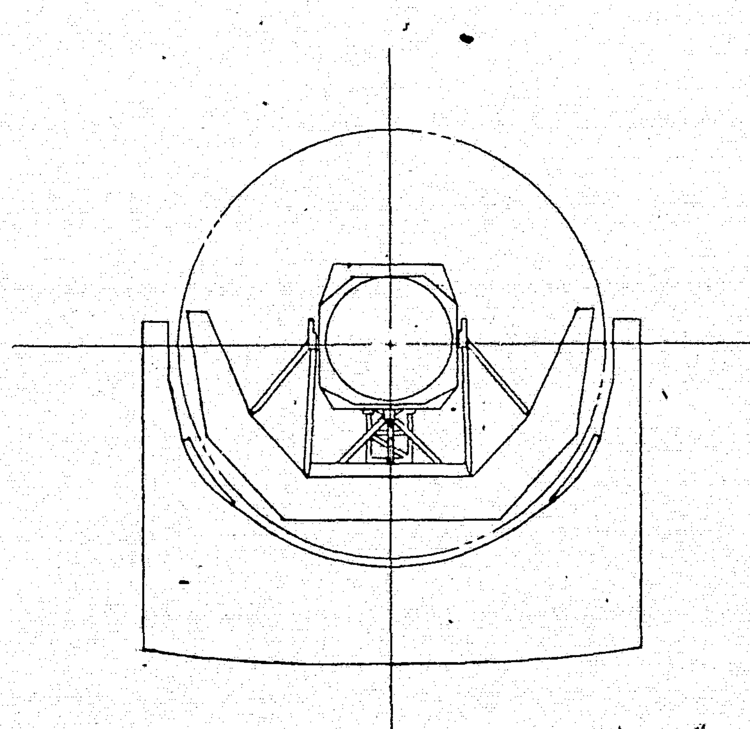
UNLATCHED



VIEW X
MANUAL VERSION
BOOST LATCH MECHANISM



A-A

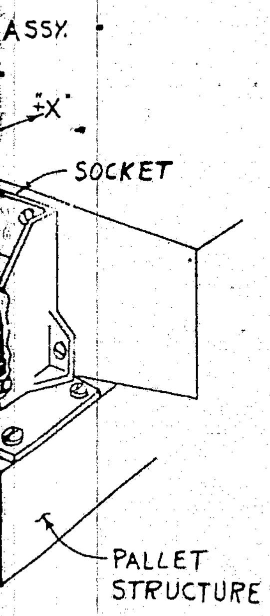


SECTION B-B

FOLDOUT FRAME 4

6 5 4

ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED



SUMMARY OF EVA TASKS

ITEM	TASK
1	RELEASE 3 FLIGHT SUPPORT LATCHES ON SUOT
2	REMOVE AND STOW SUOT BOOST COVER, OBSERVE ERECTION OF SUOT
3	RELEASE 2 LAUNCH/LANDING RESTRAINTS ON SIPS AND 4 GIMBAL LOCKS.
4	REMOVE SENSOR COVERS AND ERECT SIPS PEDESTAL, OBSERVE SIPS ERECTION
5	REMOVE FILM CANNISTERS FROM SCHWARZSCHILD AND 2 SCHMIDT CAMERAS AND TRANSPORT TO AIRLOCK

FOLDOUT FRAME 5

SD 76-SA-0026

2-29, 2-30

DR BY	F. MAYES	1-20-76
CHK BY		
APPROVED BY		

Rockwell International Corporation
Space Division
12214 Lakewood Boulevard • Downey, California 90241

ASTRONOMY SORTIE PAYLOAD

EVA APPLICATIONS STUDY

SIZE	CODE IDENT NO.	DRAWING NO.
L	03953	2617-1

SCALE 1/40 SHEET 1

II. SUMMARY OF EVA TASKS

A. Release 3 flight support latches on SUOT

B. Attach IPS to SUOT

C. Remove and stow SUOT boost cover, observe erection of SUOT

D. Release 2 launch/landing restraints on Schmidt camera SIPS and 4 gimbal locks

E. Remove 2 camera covers and erect SIPS pedestal, observe SIPS erection

F. Release 2 launch/landing restraints on IR telescope and Schwarzschild camera SIPS. Release 4 gimbal locks

G. Remove and stow covers from camera and IR telescope and erect SIPS pedestal and observe SIPS erection

H. Release 2 launch/landing restraints on UV sensor modules SIPS Release 4 gimbal locks

I. Remove and stow covers from:

UV photometer
EUV imaging telescope
IUE spectrograph
EUV spectrometer
UV polarimeter
Microchannel spectrometer
Erect SIPS pedestal
Observe SIPS erection

J. At conclusion of sortie, observe retraction of all SIPS mounted modules and SUOT. Disconnect SUOT from IPS. Replace all sensors and telescope covers, install gimbal locks and engage launch/landing restraints. Remove film canisters from Schwarzschild and 2 Schmidt cameras and transport to airlock.

III. EVALUATION OF EVA INTERFACES

A. Structures

1. Push/pull at module ends

2. Access between modules

3. Push/pull at gimbal and SIPS/FSS pedestals

4. Foot restraints on pedestals/pallet at 170 N-m (1500 in.-lb) torque

B. Film Exchange/Removal (Schmidt - 10 kg (22 lb))

1. Foot restraints on module

2. Push/pull on camera beside film cartridge

C. Deploy SIPS

1. Motor (or manual) drive

a. Mass: Several 27-36 kg (60-80 lb) up-down/left-right per SIPS
b. Time-to-deploy/retract: 3 minutes

c. (Manual) torque per concept: use hand held motor drive
d. Module/sensor sensitivity: not sensitive
e. Access: marginal

D. Materials, Surfaces, Sensors

1. Contamination sensitivity/requirements

a. UV photometer: water vapor, RCS firings
b. EUV imaging telescope: water vapor, RCS firings
c. IUE spectrograph: water vapor, RCS firings
d. EUV spectrometer: water vapor, RCS firings
e. EUV polarimeter: water vapor, RCS firings
f. Microchannel spectrometer: water vapor, RCS firings
g. IR telescope: water vapor
h. Schwarzchild camera: RCS firings
i. Scmidt cameras: RCS firings
j. UV optical telescope: water vapor, RCS firings

2. Temperature characteristics

a. Typical module: 172/340°K (-150/+150°F)
b. UV optical telescope: 166/322°K (-160/+120°F)

3. Acceleration sensitivity (translation path)

a. SIPS
b. Photometer/spectrometer modules
c. Telescope modules
d. Camera modules
e. UV optical telescope

4. Contact sensitivity

a. Pressure allowables/sensitive areas: canisters - TBD
b. Specific "work cover" requirements: none

E. Energy Sources

1. Pyrotechnics

a. Shorting plug
b. Manual jettison alternative
c. Blast/protective direction

2. AC power - 1100 watts, 120 volts

a. Access
b. Grounding

3. DC power - 4400 watts, 28 volts

4. Gases - helium

5. Cryogenics - yes

F. Operations Requirements

1. Mission/preparation time constraints
2. EVA interface design size/shape constraints
3. EVA access constraints

2.2.5 Advanced Technology Laboratory (ATL)

I. PAYLOAD DESCRIPTION (Reference Drawing No. 2511-1)

A. Advanced Technology Laboratory (ATL)

B. NASA Headquarters - ST-2; SSPD - ST-23-S

C. Space Technology

D. Spacelab and Pallet

E. 3228 kg (7102 lb); 15 m (l) (49.5 ft); 4.5 m (14.8 ft) (d)

F. GN_2, Film

II. SUMMARY OF CANDIDATE EVA TASKS

A. Microwave Interferometer

1. Unlatch each boom boost latch mechanism of cruciform extendable 38 m (125 ft) boom
2. Attach hand held power drive mechanism deploying antenna booms
3. Reversal of 1 and 2 above for entry

B. Search and Rescue Aids

1. Unlatch antenna boost locks
2. Rotate antenna to operational position
3. Reverse of 1 and 2 above for entry

C. Molecular Beam Facility and Experiments

1. Unlatch, remove and stow container cover
2. Unlatch sensor boost latches
3. Attach power drive unit and extend sensor boom
4. Reverse above procedures for entry

D. Ultraviolet Meteor Spectroscopy From Near-Earth Orbit

1. Vent container of pressurant
2. Vent contamination container
3. Unlatch, remove and stow contamination cover
4. Load film as required
5. Reverse above procedure for entry

E. Autonomous Navigation/Earth Pointing, also Autonomous Navigation/ Horizon Sensor

1. Vent container of pressurant
2. Unlatch, remove and stow contamination cover
3. Unlatch gimbal system boost locks
4. Reverse above procedure for entry

F. Lidar Measurements of Cirrus Clouds and Lower Stratospheric Aerosols

1. Vent container of pressurant
2. Unlatch, remove and stow contamination cover
3. Unlatch gimbal system boost locks
4. Reverse above procedure for entry

G. Non-Metallic Materials

1. Unlatch, remove and stow contamination cover(s)
2. Attach hand held power drive and deploy boom
3. Reverse (1) and (2) above for entry

III. EVALUATION OF EVA INTERFACES

A. Structures

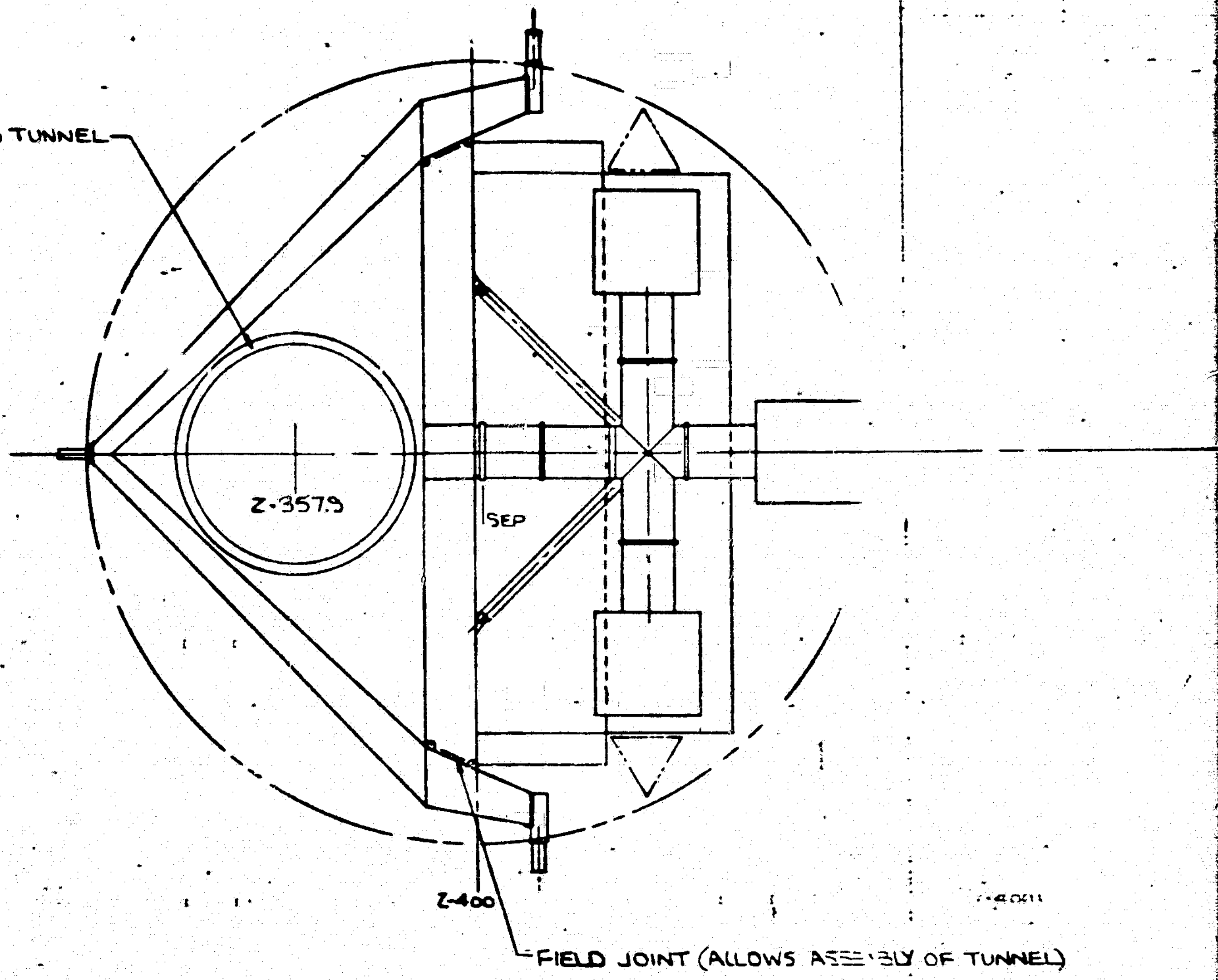
1. Twist, push and pull of latches and boost locks
2. Handhold near each latch and/or lock in excess of 0.6 m (24 in.) Foot restraints required when handhold cannot be accommodated
3. Handholds must support a push/pull torque of 34 N-m (300 in.-lb) and foot restraints 170 N-m (1500 in.-lb)
4. Personnel belt restraints required during equipment assembly (i.e., microwave radiometer horn antenna, antenna mass ∿242 kg (532 lb))
5. Removal of contamination covers and stowage. Covers range from 0.45 m (18 in.) to approximately 1.5 m (∿56 inches)
6. Astronaut body access between equipment
7. Work platform with foot restraints and belt restraints allowing rotation of equipment (i.e., side-looking radar unit, Ref. II.B)

B. Removable Modules (Maintenance)

1. Remove/replace electronics from microwave interferometer - 1 kg ea, ∿10 units
2. Remove film cassettes from UV meteor spectroscopy

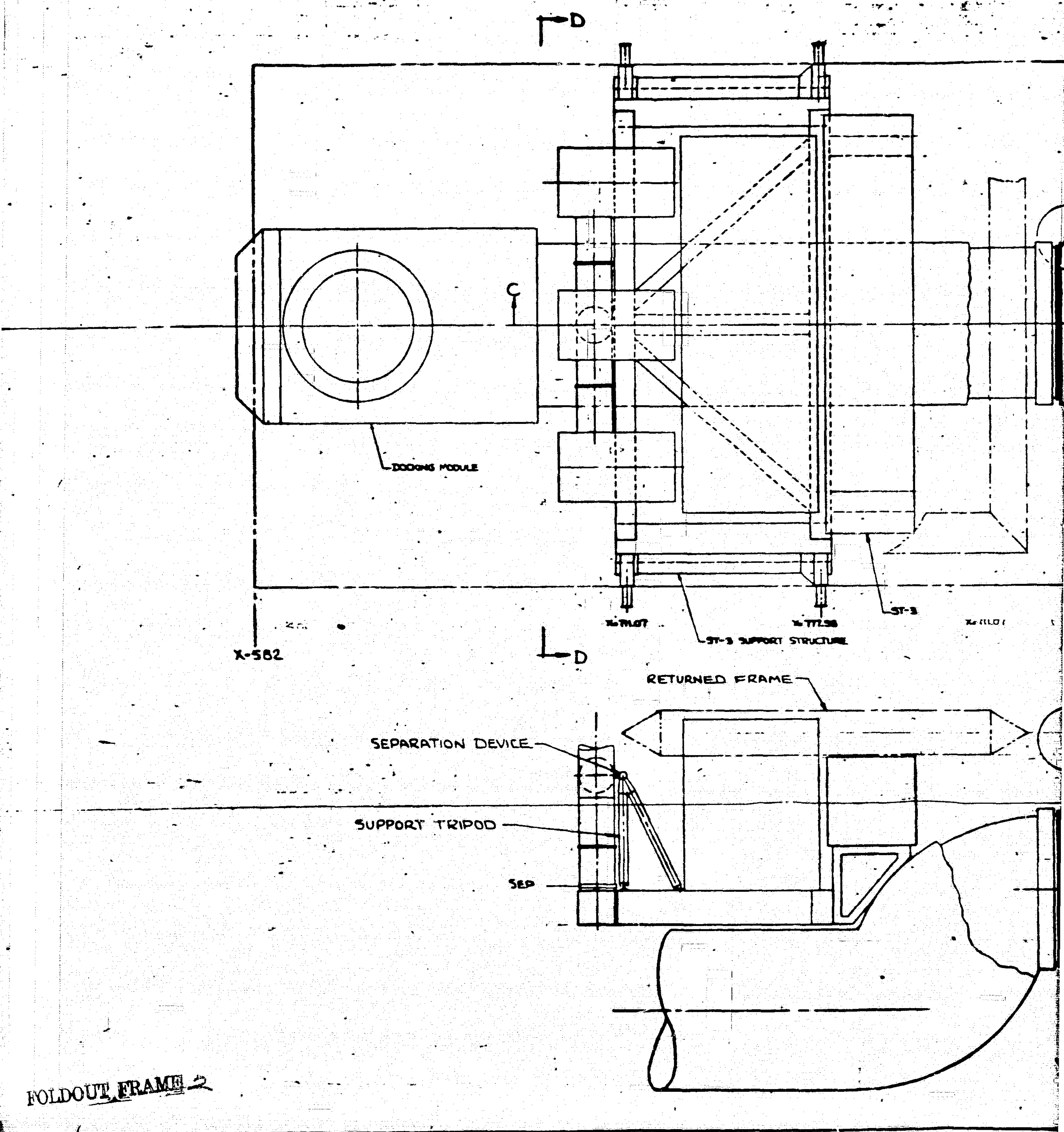
C. Movable/Extendable Elements

1. Boom deployments on
   a. Microwave interferometer; 4 booms, 38 m (125 ft) ea
   b. Molecular beam facility and experiments; 1 boom, 22.7 m (75 ft)
2. Extendable devices - Non-metallic materials; 10 m (33 ft)
3. Movable Devices
   a. Search and rescue aids; 1 antenna 9.4 m (31 ft)
   b. Molecular beam facility and experiments; 1 canister 1 m (d) x 1.8 m (1)
4. Mass of device being moved and speed
   a. Microwave interferometer; boom - 39 kg each boom, traveling at 1.2 m/sec (5 fpm)
   b. Molecular beam facility and experiment; 114 kg, traveling at 1.2 m/sec (5 fpm)
   c. Non-metallic materials; 1.2 kg, traveling at 2.4 m/sec (10 fpm)
   d. Search and rescue aids; 454 kg. Rotation time not to exceed 0.05 hour (3 minutes)



SPACELAB TUNNEL
Z-357.9
SEP
Z-400
FIELD JOINT (ALLOWS ASSEMBLY OF TUNNEL)

VIEW D-D



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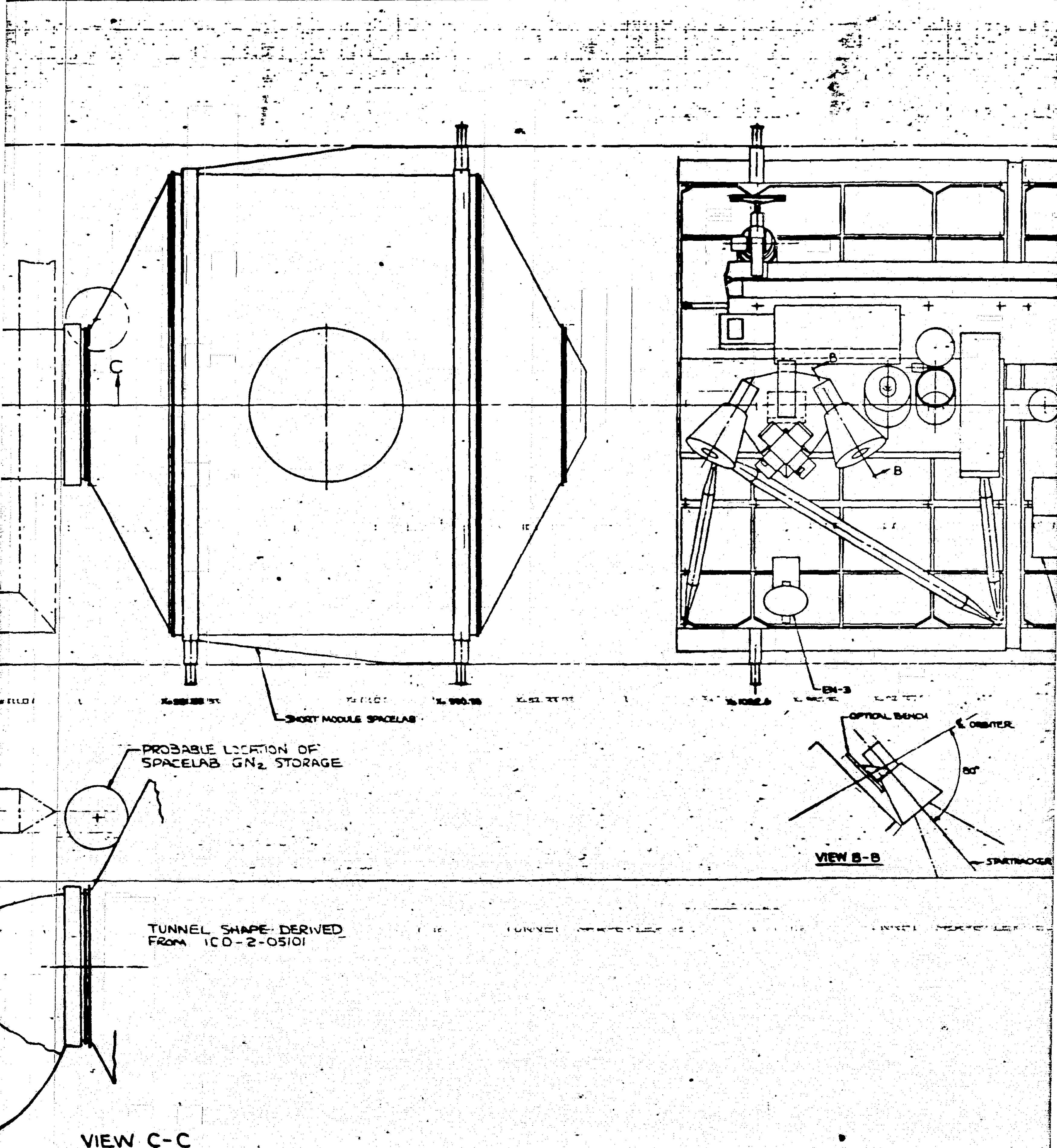

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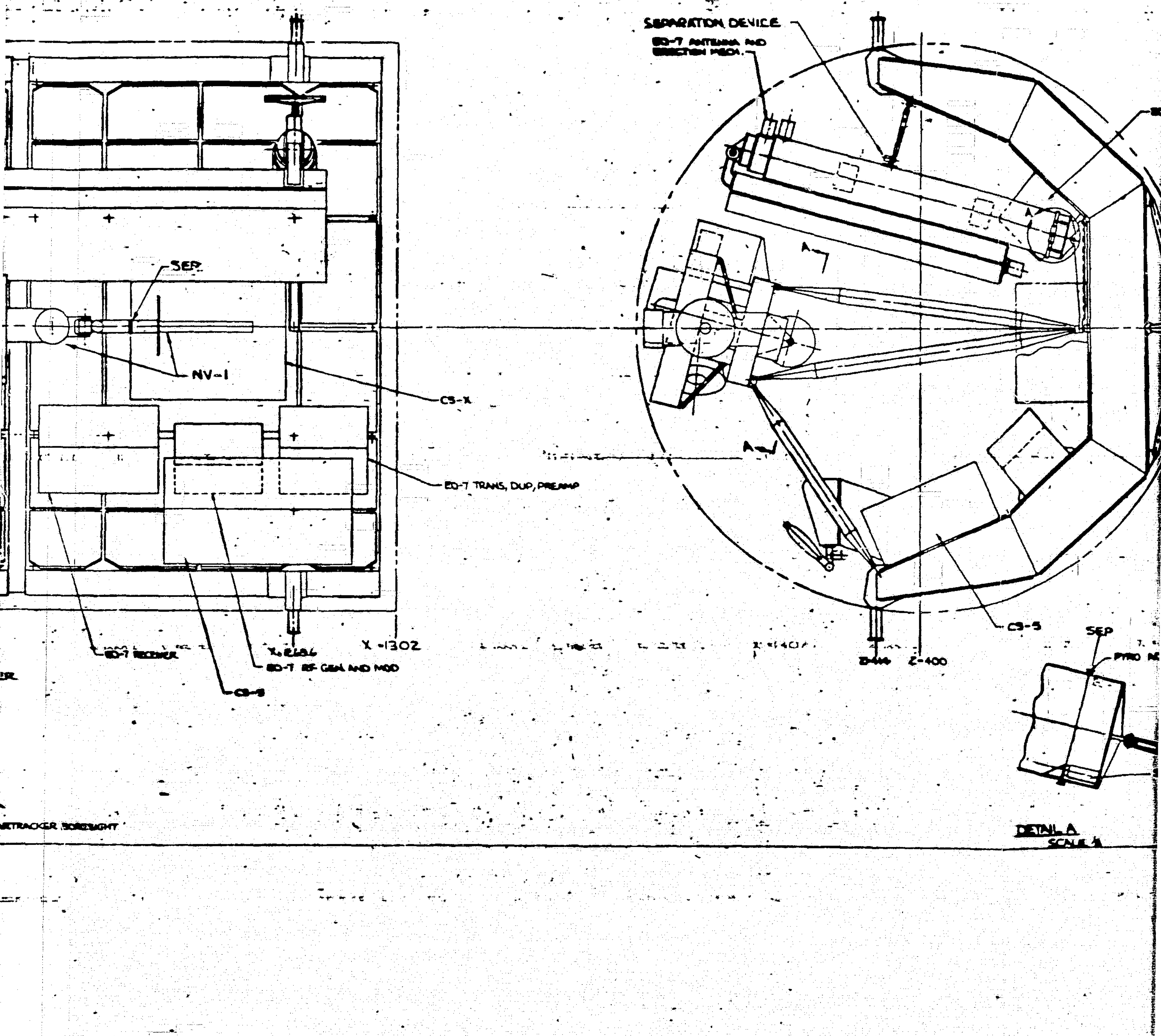
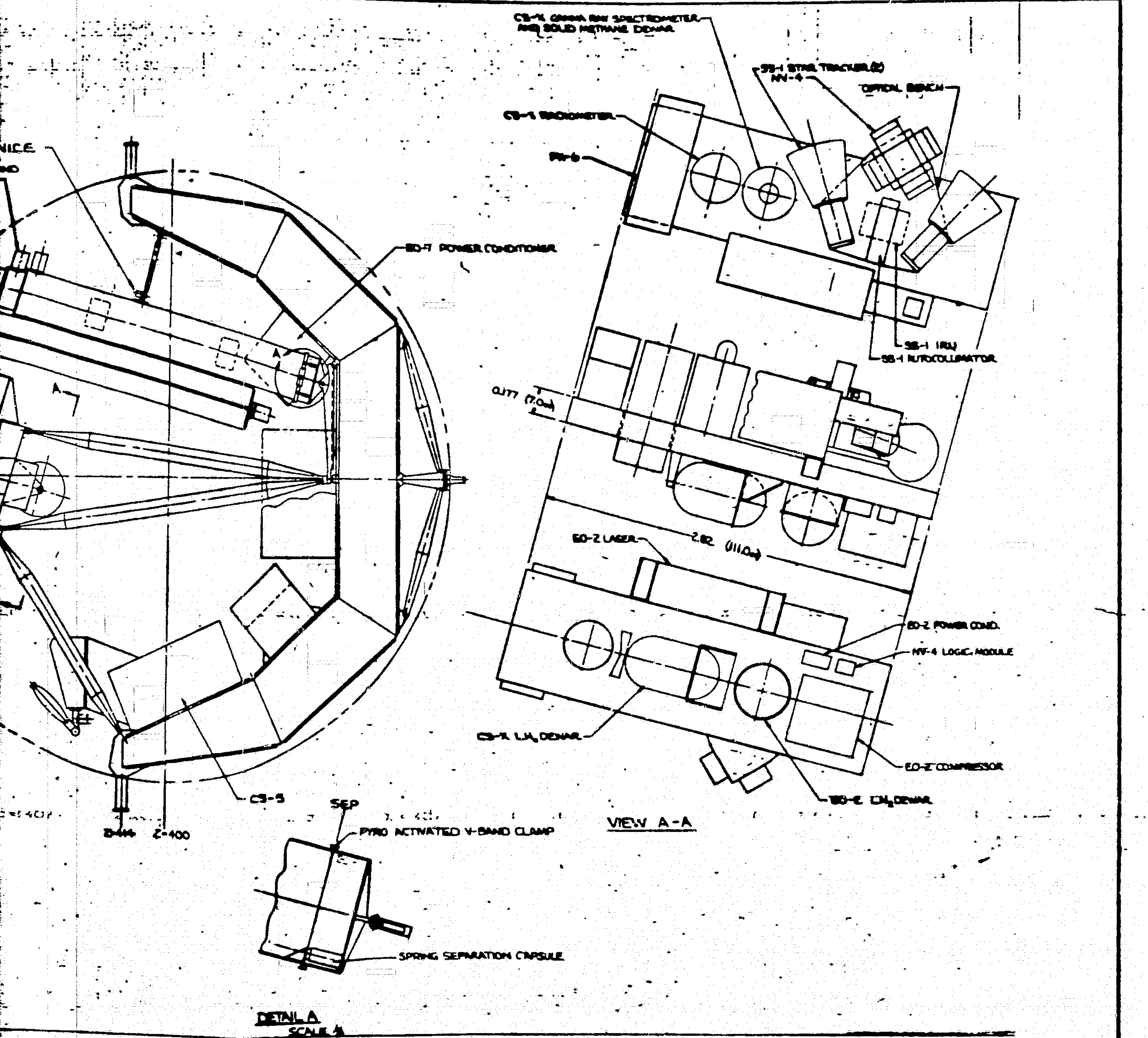


FOLDOUT FRAME 4



FOLDOUT FRAME 3

SD76-SA-0026

1/20	CLEGG	ROCKWELL INTERNATIONAL CORPORATION SPACE DIVISION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA	
PAYLOAD 1 CONCEPTUAL DESIGN ATL STUDY			2511-6

2-35, 2-36

e. Molecular beam facility and experiment; 174 kg, traveling at 1.2 m/sec (5 fpm). Also rotation of canister is required through an arc of ∿45 degrees.

5. Accessibility

a. The following items are mounted within circular containers:

(1) Microwave interferometer
(2) Molecular beam facility and experiments
(3) Ultraviolet meteor spectroscopy
(4) Lidar meteor spectroscopy and lower stratospheric aerosols
(5) Autonomous navigation/earth pointing and/horizon sensor

D. Materials, Surfaces, Sensors

1. Contamination sensitive items

a. Starfield/landmark tracker
b. TV camera
c. Spectrograph, panchromatic
d. Meteor detector photomultiplier
e. Lidar optics systems
f. Lidar receiving telescope
g. Image intensifier camera
h. Photometer
i. Pointing telescope
j. Crystal quartz microbalance
k. Non-metallic specimen

2. Temperature characteristics

a. Non-operating temperatures generally allow a temperature at the sensor to hold at a low of 278°K (41°F). The high temperature for pure structures is 339°K (151°F), and 313°K (104°F) at the sensors.

b. Operating temperatures are same as above

3. Acceleration sensitivity

a. Rotational sensitivity

(1) Microwave interferometer antenna booms
(2) Molecular beam facility and experiments
(3) Non-metallic materials specimen tray support boom

b. Translation accelerations

(1) Microwave interferometer antenna booms
(2) Autonomous navigation/earth pointing gimbal assembly
(3) Non-metallic materials specimen tray support
(4) Molecular beam facility and experiments support boom

4. Contact sensitivity

E. Energy Sources

1. Pyrotechnics

   a. Bolt charge ignitor (shorting plug)
   b. Manual jettison alternative (astronaut/AMU)

2. AC power - 115 vac maximum

3. DC power - 28 vdc maximum

4. Gases

   a. Pressurization of contamination containers. Storage
   b. Containers less than 7×10^6 N/m^2 (1000 psi)

5. Cryogenics - none

6. RF energy generated

   a. RF - search/rescue aids - TBD

7. Laser

   a. Lidar measurements of Cirrus clouds and lower stratospheric aerosols - TBD

8. Ionizing radiation - none

9. Combustables - none

10. Electrostatic charges - none

2.3 PAYLOADS CHARACTERISTICS SUMMARY

The five payloads analyzed in the study consisted of two automated spacecraft and three sortie payloads in four different scientific disciplines. The sortie payloads encompass over 20 unique "experiments". Consumables in these payloads include GN_2, LN_2, film, N_2H_4 (hydrazine), and solid state motors. Fifteen unique EVA tasks were found on the five payloads. These were performed generally two to 14 times on each mission. Operating temperatures ranged from 258 to 328°K (5.4 to 131°F). Structural temperatures identified by payloads projects ranged from 58 to 422°K (-354 to 300°F). Potential hazardous elements included RF and ionizing radiation, cryogenics, pyrotechnics, and laser. Every payload included sensors, subject to damage and contamination.

SECTION III. EMU REQUIREMENTS

This section describes current technology extravehicular mobility units and assesses on-going EMU developments. These data constitute a baseline for evaluating potential requirements. The section also presents the preliminary assessment of requirements areas, analyses of requirements and statistical analyses of integrated payloads missions.

3.1 EMU ASSESSMENT

Four specific pressure suit designs or design concepts were selected for evaluation:

1. Apollo/Skylab EMU - A7L-B

2. Advanced Extravehicular Suit (AES)

3. Shuttle EMU - JSC Concept

4. Ames Research Center Space Suit Assembly

Although some comparative data are presented in this section, it should be noted (1) that no standardized system has been adopted for measuring characteristics of EMU's, (2) only two of the suits described in this section have been fabricated--the other two reflect predicted characteristics/requirements.

3.1.1 Apollo/Skylab EMU

Following the relatively crude Gemini pressure garment assemblies (PGA), the Apollo EVA suit developed through several phases to a relatively sophisticated assembly featuring a portable life support system (PLSS) for lunar excursions. The Skylab EMU, shown in Figure 3-1, utilized the Apollo pressure garment assembly, but relied on life support umbilicals and a portable redundant oxygen supply in lieu of the Apollo PLSS backpack. EVA's on Apollo and Skylab were conducted from 34×10^3 newtons/m^2 (5 psi) cabin atmospheres, thus warranting a 25×10^3 newtons/m^2 (3.7 psi) nominal pressure level suit. The Apollo PGA and PLSS weights were as follows:

PGA plus EVA gloves, visor & ancillary equipment	27 kg	(60 lb)
PLSS/OPS	50 kg	(110 lb)

The A7L suits were custom sized to individual astronauts. The pressure suit was essentially a rubberized bladder with outer restraint fabric. Joints were constructed of dipped convolutes. Closure was effected with a full torso back zipper.

Figure 3-1. Skylab EMU (A7L)

Comprehensive measurements of the A5L (predecessor of the A7L-B) mobility ranges are listed in Table 3-1, with some data taken from A7L measurements.

Table 3-1. Apollo/Skylab Mobility Data

Mobility Data*	A5L Deg.	A7L-B Deg.
Forward flexion	20	120
Left/right lateral	0	35
Left/right rotation	–	5
Hip flexion	60	60
Flexion/extension	93	93
* Reference Figure 3-2		

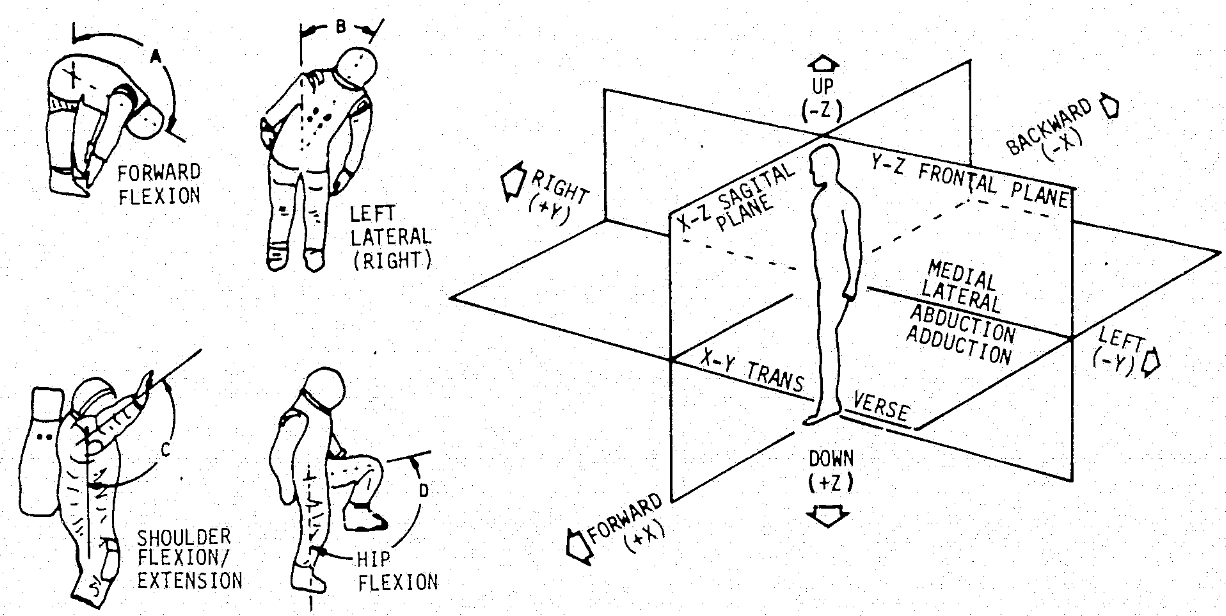


Figure 3-2. Typical Mobility Descriptions

Contamination sources of the A7L suit have been quantified. Particulate matter (dust, lint, metal) have been identified as ranging from 0.5 to 500 microns. Leakage of the suit includes 7 grams (0.016 pound) per hour (primarily O_2, CO_2, and H_2O vapor) and organics (trace gases), 0.004 grams (9.5×10^{-6} pounds) per hour. Of greatest concern perhaps is the H_2O coolant vapor from the backpack of about 0.78 kilograms (1.7 pounds) per hour (variable).

3.1.2 Advanced Extravehicular Suit

Advanced technology developments conducted in recent years are typified by the AES which stressed high mobility capability at a 5 psi operating pressure level. The suit assembly, illustrated in Figure 3-3, never proceeded to an operational configuration, consequently is shown without a thermal-meteoroid outer garment. Similarly, no life support backpack development was included in the suit development project; however, it was designed to use the Apollo PLSS. The AES was never measured comprehensively as to mobility; however, movies and other subjective data attest to its capability to approach shirtsleeve levels of motion. Table 3-2 summarizes incomplete AES mobility data. Joint design allowed good forward body bending and overall suit mobility ranges were excellent at 5 psi. The suit was constructed of multi-laminated (soft) fabrics and featured joints of rotating conical sections at the shoulder and torroidal convolute joints at various extremity locations. The waist closure was a horizontal ellipse with a circumferential clamp.

Figure 3-3. Advanced Extra-Vehicular Suit

Table 3-2. AES Mobility Data

Mobility Characteristics	AES-Degrees
Forward flexion	90
Left/right lateral	35
Hip Flexion	115

3.1.3 Shuttle EMU - JSC Concept

Recent procurement action was initiated to secure bids on EMU's for the Shuttle program. Cost and technical proposals were requested for suits and life support systems for a concept illustrated in Figure 3-4. The following data are extracted from the Shuttle EMU Request for Proposal.[1]

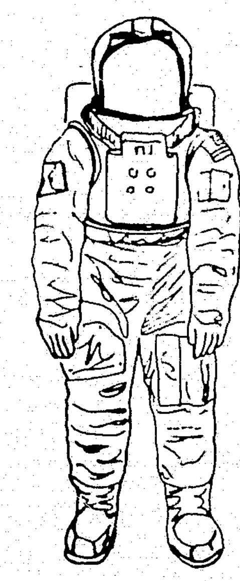


Figure 3-4. Shuttle EMU - JSC Concept

[1]Request for Proposal No. 9-BC7-4-6-1P, Space Shuttle Extravehicular Mobility Unit, dated December 12, 1975, JSC.

The EMU system concept is grouped into two major areas. These two areas consist of the life support subsystem and the pressure garment. The life support subsystem includes all the life support and cooling fluid conditioning components, while the pressure garment includes the basic anthropomorphic pressure vessel, cooling garment, and visor assembly.

The life support subsystems are housed in two modules, one integrated onto the front, the other onto the back of the hard upper torso. The back-mounted module is called PLSS/OPS (portable life support system/secondary oxygen pack). The front-mounted module is called the DCM (displays and control module). All interfaces with the hard upper torso are through panels located behind the modules. The design minimizes mounted volume and weight. The location and size of the DCM is such that the crewman can see his feet without difficulty and all displays and controls are visible and easy to reach. The DCM contains all EMU displays and controls required to allow a one man EVA. The DCM also includes the EMU battery and EMU electrical harness up to the communications carrier assembly. The DCM controls are protected to prevent the inadvertent actuation by crewman or equipment.

The back-mounted PLSS/OPS module contains the EMU expendables and machinery. The SOP is automatically actuated and is located on the bottom on the PLSS. The SOP normally remains mounted to the PLSS during flight, but is removable in flight by a trained crewman with standard tools.

The specific design of the pressure garment includes the following features:

a. Hard upper torso

b. Tucked fabric joints

c. Sealed bearings at mobility joints (shoulder, arm, and waist elements)

d. Hard ring torso entry closure with sealed bearing

e. Removable bubble-shaped helmet

f. Removable Extra Vehicular Visor Assembly (EVVA) with replaceable visors

g. Non-custom standard sizing with length adjustment provisions at the arms and lower torso

h. Non-custom standard sizing range for boots and gloves

Selected Shuttle EMU joint mobility ranges and torques as identified in the RFP are listed in Table 3-3. The additional motions are illustrated in Figure 3-5.

Table 3-3. Shuttle EMU RFP Mobility Requirements

	Mobility Range (degrees)	Torque (ft/lb)
SHOULDER MOBILITY		
Adduction/Abduction	150	1.0
Lateral/Medial	20/150	1.0
Flexion/Extension	180	1.0
ELBOW MOBILITY		
Flexion/Extension	130	1.0
WAIST MOBILITY		
Flexion/Extension	90	4.0
Rotation	150	3.0
HIP MOBILITY		
Flexion	70	2.0
Abduction	10	2.0
KNEE MOBILITY		
Flexion (standing)	120	1.0
Flexion (kneeling)	150	1.0

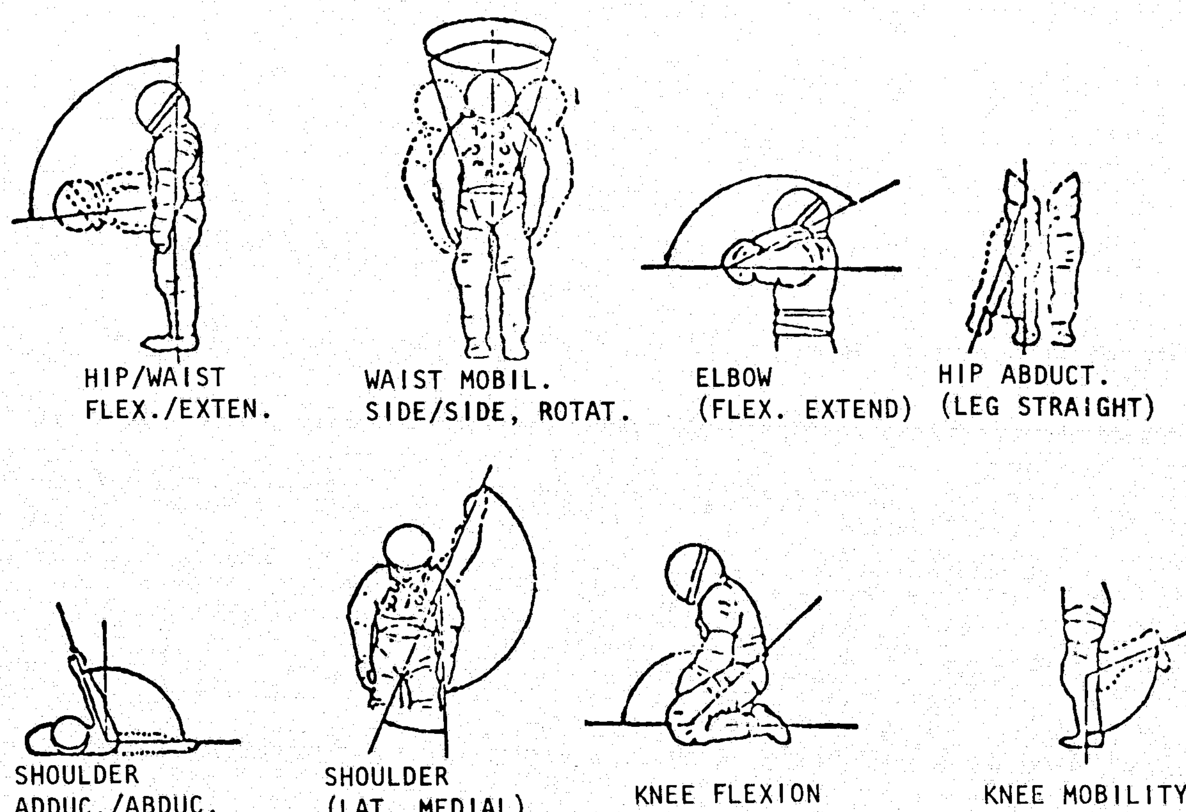


Figure 3-5. Shuttle EMU RFP Mobility Definitions

3.1.4 Ames Space Suit Assembly

Figure 3-6 shows the Ames space suit assembly (SSA) which is currently being developed as an advanced technology design.[1] A detailed review of advanced suit configurations, component developments, and mobility exercised in the AiResearch AES, Amex AX-2, and Litton RX-4 suits provided the basis for selection of the configuration shown. The SSA can be considered as a hybrid suit in that it incorporates both hard and soft suit components.

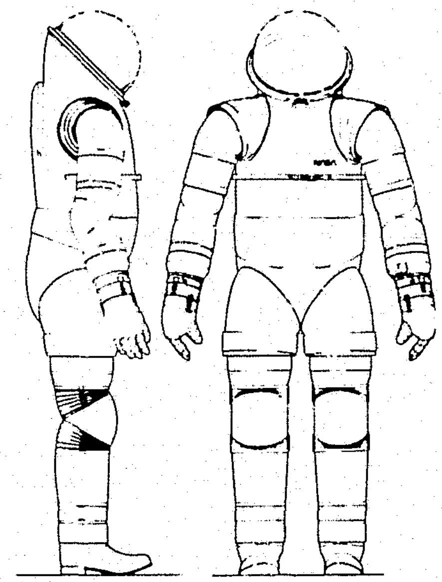


Figure 3-6. Ames Space Suit Assembly

Mobility requirements have not been defined for the suit as yet. Current plans call for the suit to be assembled for evaluation by July 1976.

A major factor in the Ames SSA is the use of 55×10^3 newtons/m^2 (8 psi) internal operating pressure, in comparison to the 28×10^3 newtons/m^2 (4 psi) Shuttle EMU. Use of the higher pressure level permits EVA without an oxygen prebreathing period.

Figure 3-7 compares the preparation time requirements between 55×10^3 newtons/m^2 (8 psi) and 28×10^3 newtons/m^2 (4 psi) space suits prior to egress from the Orbiter airlock and entry to the Orbiter payload bay. The use of the 55×10^3 newtons/m^2 (8 psi) suit is estimated conservatively to require 1.5 hours of preparation time compared with approximately 3.5 hours for the lower pressure garment for routine operations. The major influencing factor is that of the oxygen prebreathing required for approximately 2 hours prior to EVA equipment preparation suit donning, final equipment checkout, and the airlock operations. It should be noted that certain other crew activities could be performed during the early prebreathing period by use of portable oxygen masks. EMU design characteristics and airlock operations also affect time-to-egress as noted on the bar chart.

Factors other than prebreathing which affect preparation time include depressurization of the airlock, 5 minutes. However, operational constraints will usually require intermediate pressure levels between 9×10^3 newtons/m^2 (14.7 psi) and zero to verify suit integrity, with perhaps 10 to 15 minutes being a reasonable minimum. Suit donning time, which has potentially been as low as 5 minutes, can also be expected to require time just to ensure confidence in proper preparation. Shuttle EMU and advanced technology design concepts should simplify donning with torso closure and pre-installed backpack.

(1) NASA TMX-62,515 "High Pressure Space Suit Assembly," H. C. Vykukal and B. W. Webbon, Ames Research Center, December 1975.

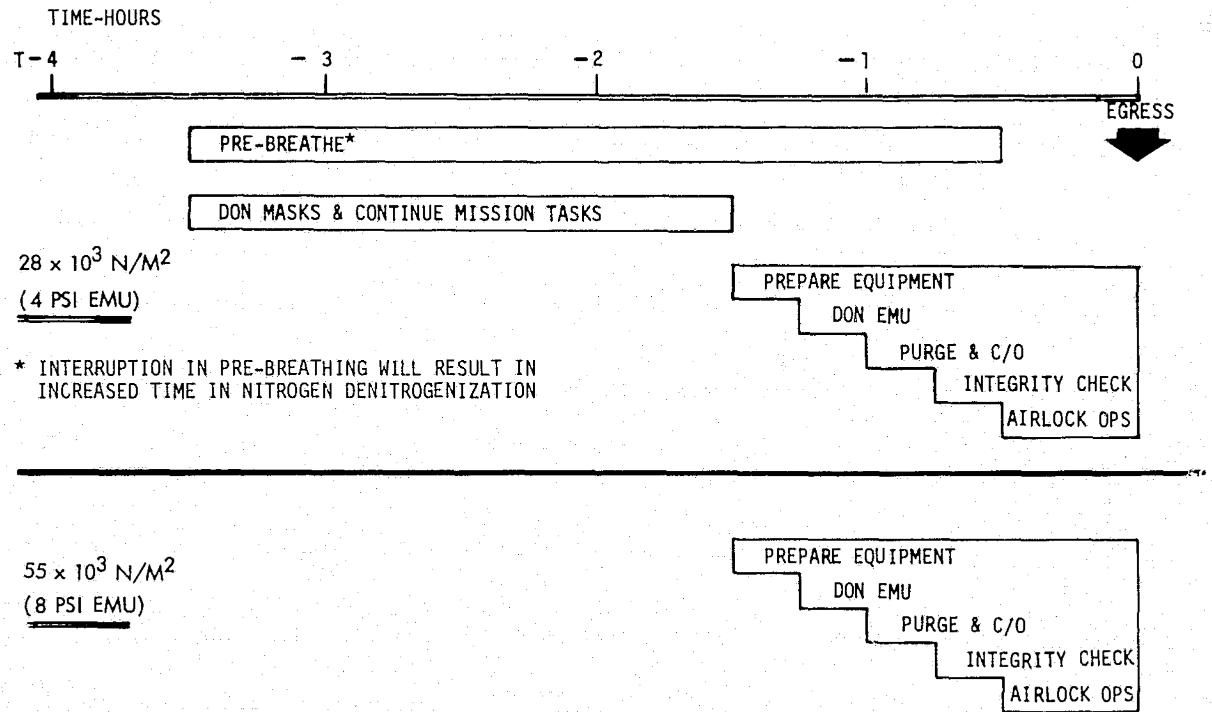


Figure 3-7. EVA System - Response Time

3.2 PRELIMINARY ASSESSMENT OF PAYLOAD RELATED REQUIREMENTS

In comparison to previous EMU requirements developments, this study was performed to identify requirements resulting from the application of EVA to Shuttle payloads. As defined in the referenced EMU RFP, the Space Shuttle program requires EVA in support of payload, vehicle contingency, and emergency operations. Typical tasks identified in the RFP are:

a. Inspection, photography, and possible manual override of vehicle and payload systems, mechanisms, and components.

b. Installation, removal, and transfer of film cassettes, material samples, protective covers, and instrumentation.

c. Operation of equipment, including assembly tools, cameras, and cleaning devices.

d. Cleaning of optical surfaces.

e. Connection, disconnection, and stowage of fluid and electrical umbilicals.

f. Repair, replacement, calibration, and inspection of modular equipment and instrumentation on the spacecraft or payload.

g. Replacement and repositioning of antennas.

Preliminary analyses were made of requirements so as to penetrate potential problem areas before conducting meetings at the NASA centers and to allow systematic evaluation of requirements. It was determined initially that requirements would fall into one of three groups: crew protection, crew performance, and payload protection. Twenty requirement areas or types were identified as falling into these three groups.

Requirements for the three groups were analyzed as to the derivation source. For example, flammability requirements for protection of the crewman would primarily be dependent on design characteristics of the payload; i.e., oxidizer/fuel elements in the makeup of the payload. Thermal protection is dependent on design characteristics (equipment mass, α/ε surface characteristics, etc.), operational characteristics (Beta angle, payload attitude, etc.), and crew tasks (e.g., RTG coolant jacket removal).

In comparison, requirements relating to crew performance are primarily derived from the tasks or activities performed by the EVA crewman. For example, load bearing points (force interfaces) may be established when crew tasks define force reaction locations. Mobility ranges can best be established by body attitudes and limb movements required to perform tasks. The analyses deliberately excluded any EMU requirements which could be derived (or influenced) solely by crewman physiological characteristics and by environmental requirements. It is believed that such requirements have received ample attention in the past. Furthermore, where such requirements were already established and determined to be at levels which would override payload interface derived requirements, no further evaluation was performed.

3.2.1 Detailed Level of Analysis

Payload designs, payload (mission) operations, and EVA tasks which could influence requirements were analyzed and listed, based on their pertinent elements. Candidate generic EVA tasks summarized from the analyses described in Section II, were listed; e.g., latch mechanism operation or boom assembly, etc. Payload design characteristics also described in Section II, which influence EMU requirements were established; e.g., mass properties and surface finishes which determine thermal properties, types of fluid systems which could influence material selection, etc. Mission characteristics were defined as to desired orbit, attitude constraints, etc., as they affect EMU thermal and radiation protection. Finally, EMU characteristics as identified in the first part of this section, which could affect payloads were established. Table 3-4 summarizes these characteristics by each of the above categories and relates the requirement type to the characteristics. The data presented also serves as a checklist for the review of requirements presented later.

Table 3-4. Characteristics/Requirements Matrix

SYSTEM ELEMENT	I. Crew Protection									II. Crew Performance							III. PL Protection			
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	1	2	3	4
	Flammability	Thermal	Durability	Dielectric properties	Radiation resistance	Penetration/abrasion	Fluid resistance	Impact resistance	Bio-contamination	Reaction time	Force interfaces	Mobility	Visibility/orientation	Communications	Operating time	Reliability/maintain.	Contamination	EMI/EMC	Dielectric properties	Surface damage
PAYLOAD DESIGN																				
Cryogenics	X	X					X													
Gases/pressure	X	X				X														
Hypergolics	X						X													
Other liquid/chemical	?	?					X													
Operable equipment		X		X																
Structure shape/mass		X				X		X				X	X	X						
Replaceable components		X		X								X			X					
Antennas		X			X									X						
RTG's		X			X					X										
Radiators		?					X						X							
Coldplates		X					X													
Bio-systems									X											
S/C surfaces		X	X	X		X							X				X			
Electrical components	X			X																
Failure modes										X					X				X	
PAYLOAD MISSION																				
Altitude		X			X															
Inclination		X			X															
Launch time		X																		
Attitude		X																		
Payload separate/retrieve		X																		
EVA excursions			X		X															
EVA TASKS																				
Latches - open/close		X	X								X	X			X	X				
Boom assembly/disassembly		X	X								X	X	X		X	X				
Extendibles-drive/retr.		X	X								X	X	X		X	X				
Antenna/array-instl./rem.		X	X								X	X			X	X				
Component R&R		X	X		X						X	X			X				X	
Cover remove/install		X	X								X	X			X					
Umbilical make/break		X	X								X	X			X	X				
Translation								X							X					
EMU OPERATIONS																				
Water sublimation																	X			
Gas leakage																	X			
Fabric/covering																	X		X	
Antenna																		X	X	
Batteries/power																		X		
Visibility																				X

3.2.2 Mission Operations Analysis

Timeline data from the EVA study were extrapolated to all 572 payload flights to assist in deriving sizing requirements for life support, EMU life cycles, payload required exposure to the South Atlantic anomaly, and EVA durations. The traffic model data were also used in determining task frequencies and total EVA's.

Numerical summaries were made where requirements would be influenced by frequency of occurrence of EVA with respect to mission elapsed time, EVA duration times, and number of EVA's per mission. Figure 3-8 presents one MSFC traffic model mission with multiple payloads. Six candidate EVA work periods are shown which are compatible with crew work cycles. Using candidate tasks and task timelines from the "EVA" study, the following mission sequence was developed. (1) Two crewmen egress on the first EVA opportunity, and independently prepare the BESS module for separation. During a remote checkout period, they jointly prepare a space processing sortie for operation. Upon completion of this task, final work on the BESS is accomplished through spacecraft separation. (2) During the second EVA opportunity the two crewmen support Space Telescope docking and preparation for maintenance. Maintenance tasks are completed on two subsequent EVA's, followed by separation tasks. (3) The fifth EVA opportunity is employed in performing EVA tasks associated with docking and stowing two satellites in preparation for entry. (4) The sixth EVA period activity consists of entry preparations on the sortie payload.

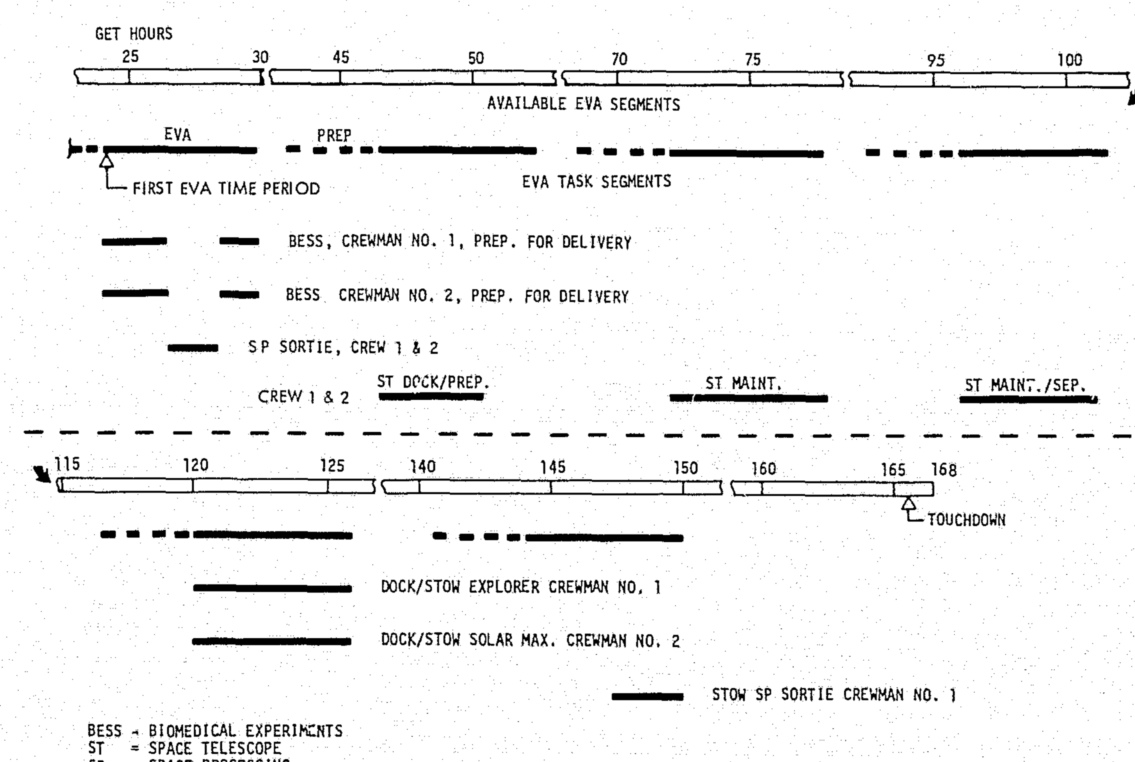


Figure 3-8. Integrated Mission Timeline

Table 3-5 summarizes the mission operations analysis. Details are also included as appropriate in individual requirements dicussions. The data in the table were prepared by summing EVA times on multiple payload missions. In this respect, the data were not optimized as they could be if each mission were analyzed separately, and accounts for one 3-man EVA occurring. The traffic model data called for various combinations of spacecraft delivery, retrieval, on-orbit maintenance or sortie mode. In general, deliveries were accomplished in the first or second period, on-orbit maintenance in the second (and subsequent if required) followed by retrievals. Sortie payloads were normally set-up in the first period and stowed in the sixth. Of interest in the table are that most EVA's (about 65 percent) are one man, that 50 percent of the EVA's occur in the first opportunity, and that 63 percent of the missions have two EVA's (89 percent have 2 or less).

Table 3-5. EVA Mission Statistics

Flights

Type	Total No.	With EVA	Without EVA	% With EVA
NASA & Other Non-DoD	418	382	36	91
DoD	155 573*	142**	13**	

*Includes One OFT Flight
**Based on 91 Percent, Above

EVA Statistics - NASA & Other Non-DoD Only

Type	Mission Available EVA Period 1	2	3	4	5	6	Total
EVA Hours	1235	267	170	70	61	580	2383
No. EVA's, 1-man	249	57	28	6	8	147	495
2-man	132	32	22	11	8	66	271
3-man	--	1	--	--	--	--	1
Total EVA's	381	90	50	17	16	213	767
Avg. Hours/EVA	3.24	2.96	3.4	4.11	3.81	2.72	3.1
% of EVA's (767)	50	12	6	1	2	30	--

No. EVA's per Mission

Missions	0	1	2	3	4	5	6	
Total Missions	36	70	264	34	6	5	3	418
Total EVA's	0	70	528	102	24	25	18	767
% of Missions	9	17	63	8	1	1	1	--

One additional set of statistical data were established to use in the requirements evaluation. This consisted of a more detailed set of task identifications and an extrapolation of the frequency of occurrence of these tasks. These data are summarized in Table 3-6. The table was compiled from "EVA" study data as to the number of times a task was performed on each of the 13 representative payloads. This number was then multiplied times the number of times each payload in the representative group was flown. For example, the Space Telescope was determined to have three removable sensor contamination covers. There are 38 deliveries of this type of spacecraft--3 x 38 = 114 task performances.

Table 3-6. EVA Task Occurrence Frequency

Planned EVA Tasks	No. Times Performed
Remove and stow contamination covers	2,234
Unlatch boost locks (antennas, booms, panels, sensors)	10,159
Antenna erection and latching	585
Solar array erection and latching	163
Boom erection and latching	1,260
Sunshade deployment	358
Mechanisms erection/deployment	151
Film loading	495
Cryogenic loading	109
Instrument pointing system attachment	80
Sample/specimen installation	116
Pyrotechnic shorting plug removal	3,008
Launch subsatellites	58
Launch deployable units	348
Point/scan instruments	464
Umbilical disconnect	313
Disengage spacecraft (boost latch release)	942
Docking latches release for docking	560
Connect umbilicals	136
Install safety items	221
Clean sensors/experiments	120
Service fluid systems	28
Retrieve/install contamination covers	1,985
Engage entry latches	8,769
Remove/stow/retract antenna	543
Remove/stow/retract solar arrays	151
Boom retraction and latching	1,209
Sunshade retraction and latching	344
Mechanism retraction and latching	145
Release RMS and stow	140
Film retrieval	495
Cryogenic supply vent/stow	109
Sample retrieval	116
Shorting plug installation	2,376
Drain/purge fluid system	188
RMS engagement	255

3.3 REQUIREMENTS EVALUATION

Each of the requirements areas listed in Table 3-4 are discussed individually in this subsection. Final conclusions and recommendations are presented in Section IV.

3.3.1 Flammability

Flammability is the characteristic of material to either burn with a flame or rapidly oxidize as in an explosion. It is related to those materials which are associated with the personal crew provisions and non-metallic materials of the EMU.

The review of payload characteristics and flammability criteria indicate that the EMU will not be susceptible to flammability due to external sources of ignition (parag. 3.3.4 discusses electrical systems as sources of ignition). In order to maintain flame propagation there must be a flame supporting oxidizer and a surrounding pressure. Therefore, should the EMU be engulfed in an oxidizer the lack of a surrounding pressure at the Shuttle orbiter altitude will not support combustion.

Certain types of hypergols and propellants (i.e., flourines, nitrous oxides) have been known to ignite at pressure altitudes of about 90 kilometers (300,000 feet) but it is not anticipated that these exotic materials will be used due to the difficulty of handling and storage.

The critial area of concern is within the EMU itself. The suit will be operating anywhere from 26 to 55 x 10^3 newtons/m^2 (3.7 to 8 psi). Should a two-gas system be used, O_2/N_2 mixture, its environment would be less susceptible to flammability than pure O_2. In lower pressure suits 100 percent oxygen is used. It becomes difficult to select material which is flame proof and yet comfortable for the wearer. Therefore, any electrical system, both biomedical and the EMU electrical system, must be designed and built such as not to become the ignition source internally to the EMU or the portable life support system. Typical requirements are defined.[1]

3.3.2 Thermal Interface-Crew Protection

This interface consists of payload equipment external thermal conditions which can occur from long duration space viewing (coolant), direct solar heating, and artificial heating sources carried within the payload.

Natural Thermal Environment

The thermal dynamic range of the Shuttle orbiter bay is dependent on the inclination, the altitude of flight, and the orbiter attitude. For example, with an empty bay, earth pointing and belly toward earth the liner temperature (X_o = 760 to 919) will approach 115°K (-250°F). High temperatures are reached at about 366°K (200°F) with the bay toward the sun and the X axis perpendicular to the direction of solar flux (X_o = 1191 to 1307). Figure 3-9 illustrates temperature ranges for the empty cargo bay under typical conditions.

[1] MSC Design and Procedural Standard, JSC M-8080, Standard No. 130

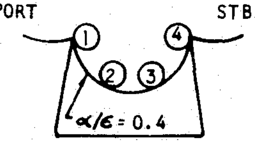
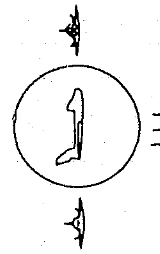
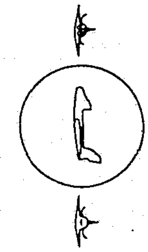
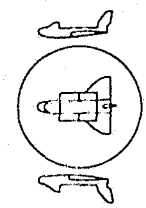
DATA POINT LOCATION PORT STBD  DEGREES F.	BOTTOM TO SUN  SOLAR FLUX	TOP TO SUN  SOLAR FLUX	TAIL TO SUN  SOLAR FLUX
X_o = 582 to 760			
1	-107.6	146.3	-203.5
2	-117.6	193.6	-230.7
3	- 84.9	187.2	-230.0
4	- 51.7	130.5	-203.7
X_o = 760 to 919			
1	-112.0	142.3	-216.5
2	-124.5	181.3	-249.7
3	- 82.1	172.5	-240.8
4	- 46.5	123.4	-217.0
X_o = 919 to 1191			
1	- 91.7	140.2	-164.9
2	-114.9	181.9	-211.7
3	- 78.0	173.7	-211.6
4	- 38.5	121.7	-164.7
X_o = 1191 to 1307			
1	- 98.1	136.8	-164.5
2	-118.3	195.5	-228.8
3	- 88.9	190.7	-224.5
4	- 52.2	124.4	-160.0

Figure 3-9. Typical Orbiter Cargo Bay Empty Temperatures - °F

As a function of many variables, e.g., types of materials, coatings, configuration, and extraneous heat sources, a continuous transient temperature determination of payloads would require extensive analysis. Therefore, simplifying assumptions were made as to specific conditions and payload configurations, so as to analyze potential thermal interfaces. The analysis was performed to evaluate criteria[1] previously defined for EVA equipment design:

> ". . . The EMU shall provide sufficient thermal insulation to maintain . . . . contacts . . . . by an object with a surface temperature between -180°F and +200°F" . . .

However, there may be instances where this becomes rather unsuitable for a variety of activities using EVA, and may be too stringent a requirement to impose on all payloads in a variety of operations.

The analysis was conducted to provide some insight in the prediction of Shuttle payload hardware maximum surface temperatures to which the EMU could be exposed in payload deployment EVA. Since the extensive effort required for transient temperature analyses was not within the scope of this study, data were developed on equilibrium temperature as a function of the surface solar absorptance to infrared emittance ratio (α_s/ε) for four conditions of general use.

[1]Request for Proposal No. 9-BC7-4-6-1P, Space Shuttle Extravehicular Mobility Unit, dated December 12, 1975, JSC.

Figure 3-10 presents equilibrium temperatures based on a severe orbital heating environment for typical hollow boom sections for three typical surface finishes, stored vertically in the payload bay as shown. More severe heating environments than that assumed are possible but their occurrence in actual flights is unlikely. Two orbiter bay average temperatures, 339°K and 365°K (150°F and 200°F) are plotted in the figure. The 365°K value is considered a reasonable upper limit for the bay average temperature although localized areas could be significantly higher. As the boom sections are placed in operational position out of the orbiter bay, the temperature will drop toward the values given in Figure 3-11.

The equilibrium temperatures given in Figure 3-11 would be representative of the space telescope or other retrieved spacecraft. As noted on the figure, only circumferential average temperatures are given. However, they are a reasonable representation of actual temperatures provided that the surfaces are not insulated from the telescope inner structure and the telescope inner surfaces have a high emittance for good cross radiation. For those exterior surfaces well insulated from the telescope structure (for example, the outer layer of a multi-layer insulation blanket on the telescope), the maximum equilibrium temperature would be near that obtained from Figure 3-12.

A maximum equilibrium temperature for deployed solar panels can be readily obtained from Figure 3-12 provided the backface of the solar panels has an emittance equal to the front face emittance. A solar absorptance of 0.73 and an infrared emittance of 0.78 is typical for a solar array (α_s/ε of 0.94). As explained in the note of Figure 3-11, the solar panel temperature is obtained by using one-half the solar panel α_s/ε ratio; i.e., 0.47, or about 322°K (120°F).

Figure 3-13 presents equilibrium temperatures for a small plate positioned vertically in the lower portion of the orbiter bay as shown in the figure; both sides of the plate are assumed radiating to the orbiter bay and space. If the side of the plate not receiving solar heating is well insulated, that side could be considered adiabatic and the plate equilibrium temperature for that condition can be obtained by using an α_s/ε ratio twice the actual value of the front face. Maximum surface temperatures of zero power dissipation equipment boxes in the orbiter bay are estimated to be within the temperature range defined by the two conditions discussed. For example, if a box located in the lower portion of the bay (components located higher in the bay generally will have lower equilibrium temperatures) is painted with a white paint having an α_s/ε ratio of 0.4, the maximum surface temperature of the box could be expected to be in the range 365°K to 389°K (200°F to 240°F) based on the information presented. One should be cautioned that this can be treated only as a guideline range; there are some untypical but potential conditions where higher equilibrium temperatures could occur.

On the cold end of the scale, reasonable minimum surface temperatures were calculated from the data of Figure 3-9. Minimums and maximums (as discussed above) for typical EVA tasks are listed on Table 3-7, with estimates of glove grasping time. Lower temperatures than shown are possible but unlikely.

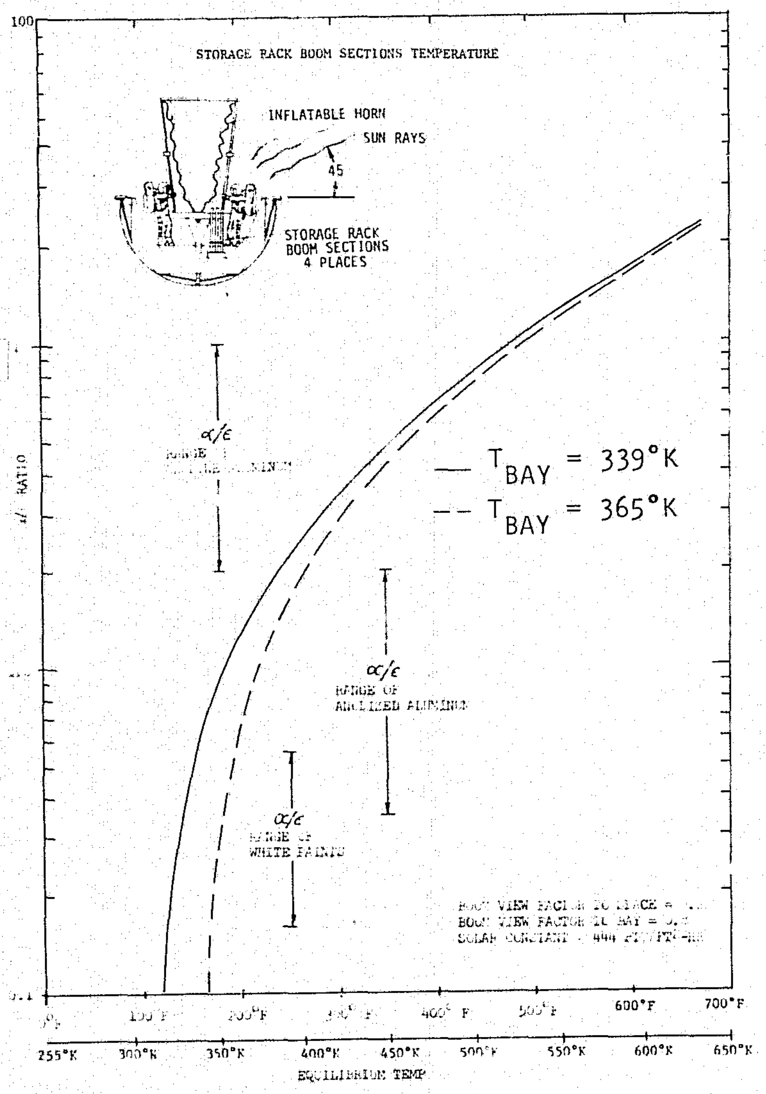


Figure 3-10. Equilibrium Temperatures Based on Severe Orbital Heating

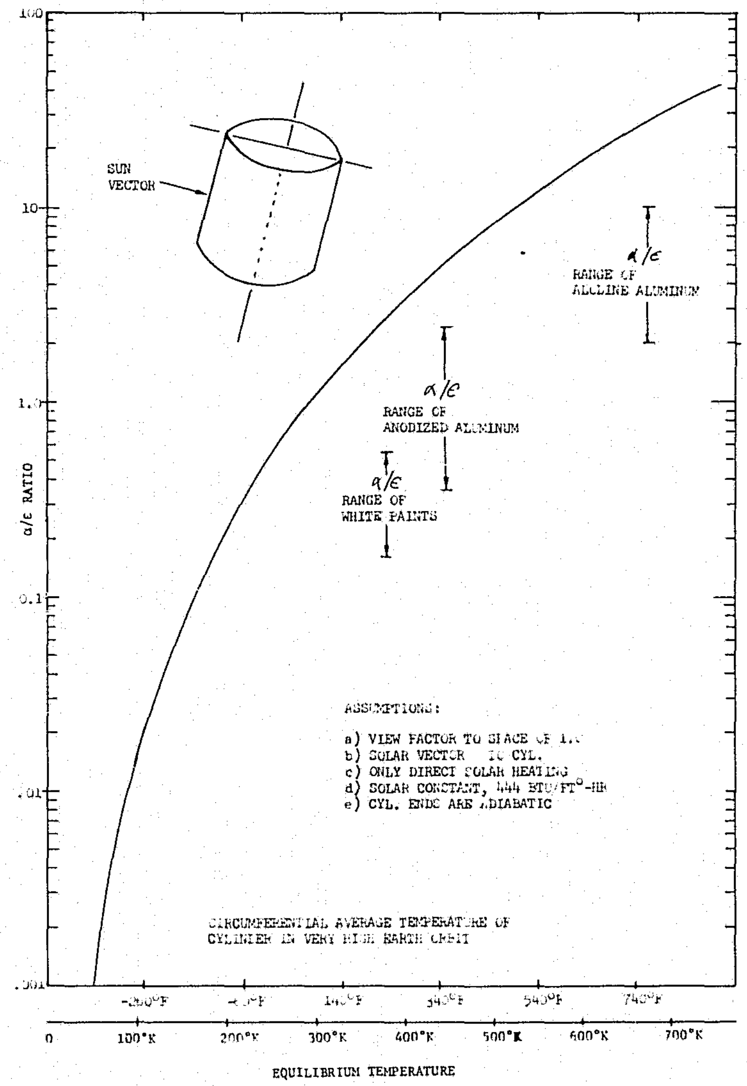


Figure 3-11. Equilibrium Temperatures in Very High Earth Orbits

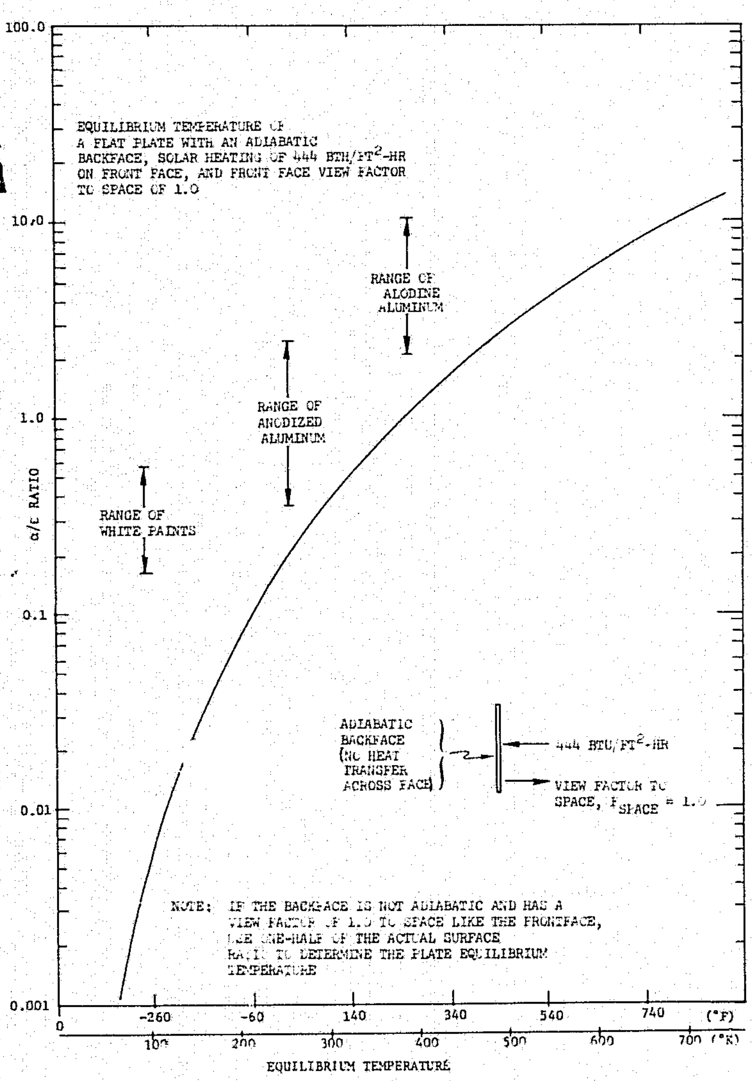


Figure 3-12. Equilibrium Temperatures of Adiabatic Flat Plate

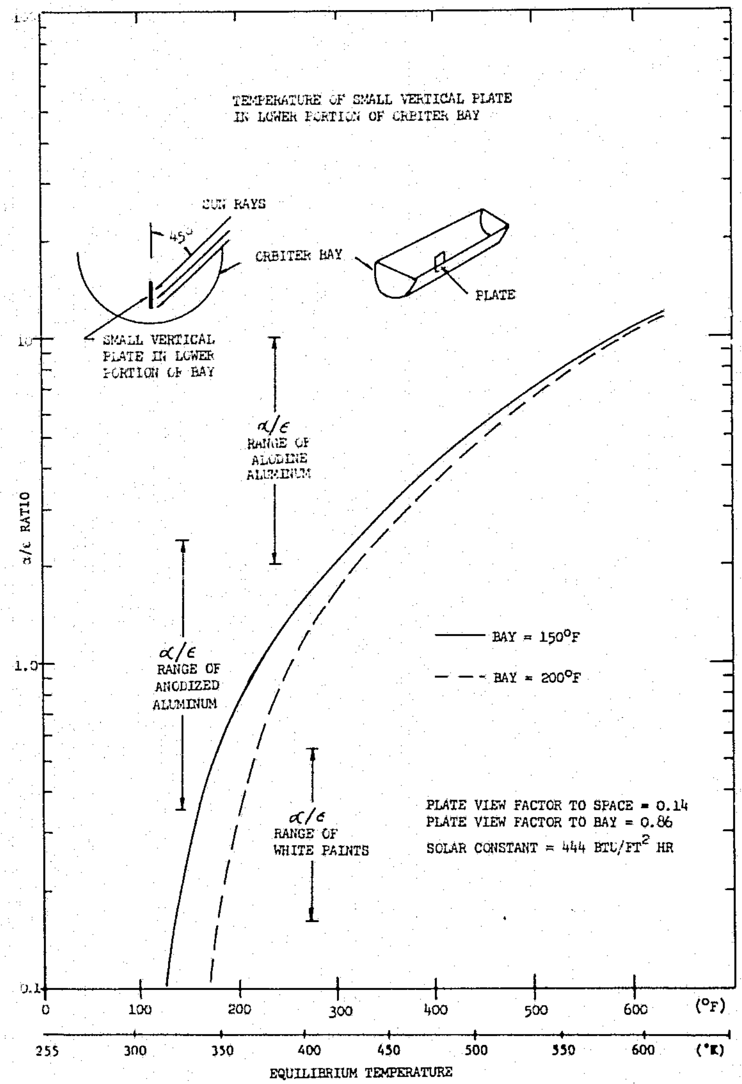


Figure 3-13 Equilibrium Temperatures in Lower Portion of Orbiter Bay

Table 3-7. EVA Thermal Interfaces

EVA APPLICATIONS	TEMPERATURE (°F) LOW	TEMPERATURE (°F) HIGH	GRASPING DURATION MIN:SEC
PRE-OPERATIONS			
REMOVE CONTAMINATION SHIELDS	-217	130/250	00:30
DISENGAGE BOOST LOCKS	- 20	165	00:15
INSTALL-ERECT-EXTEND			
Antennas	- 20	165	02:45
Solar Arrays	-120	115	02:00
Instrument & Booms	-230	140/215	02:45/15:00
Sunshades	-217	- 50	01:00/03:00
Mechanisms	- 30	250	00:15/16:00
ENGAGE RMS	- 20	165	00:15
LOAD FILM	- 60	80	15:00
VISUAL INSPECTION	- 20	-5/+310	00:45
REMOVE PYRO SHORTING PLUGS	- 20	80/220	00:05
SEPARATE SPACECRAFT			
REMOVE UMBILICAL	- 60	200	00:30/02:00
DISENGAGE SPACECRAFT	-210	-5/310	00:30
DOCKING OPERATIONS			
RELEASE BOOST LOCKS	-165	140	00:15
CONNECT UMBILICAL	-210	180	00:30/02:00
PLANNED MAINTENANCE			
INSTALL PROTECTIVE COVER/SAFETY STEMS	-210	180	00:30
INSPECT SPACECRAFT	-200	-60/200	00:45
ACCESS SPACECRAFT AND SPARES	-140	60	01:45
REMOVE & REPLACE EQUIPMENT	- 25	200	20:00
CLEAN SENSORS	- 80	138	00:05
REPAIR MECHANICAL ITEMS	-230	-5/310	Undeterm.
PREPARE FOR RETURN			
INSTALL CONTAMINATION SHIELDS	-210	180	00:30
ENGAGE ENTRY LATCHES	-164	140	00:15
REMOVE, STOW & RETRACT			
Antennas	+ 60	160	02:45
Solar Array	-200	115	02:00
Instrument and Booms	-200	140/215	02:45/15:00
Sunshades	- 80	130	01:00/03:00
Mechanisms	-125	240	00:15/16:00
ENGAGE RMS	-217	146	00:15
RETRIEVE FILM	- 60	80	15:00
STOW/LOCK REMOVED COMPONENTS	- 25	200	20:00
RETRIEVE SAMPLES	- 25	410	05:00
INSPECT FOR ENTRY	-200	-60/200	00:45
INSTALL SHORTING PLUGS	- 25	80/220	00:05

In general, thermal control coatings and protection systems will not tolerate excessive handling since damage to these items could occur. Therefore, anodized aluminum is a more likely EMU interface. Solar panels are subject to damage upon direct contact; however, the temperature data given here would conduct to the structured members. Potential payload damage is discussed later. It is probable that built-in handholds or portable handles carried by the EVA crewman would be used to move payload peripheral equipment. Handling devices could be designed to eliminate the problem of very high or low touch temperatures.

The Global Positioning Satellite (GPS), NAVSTAR, thermal design indicates surface temperatures in the range 144°K to 365°K (-200°F to +200°F) can be expected. Skylab thermal data indicates surface temperatures in the range of 89°K to 422°K (-300°F to +300°F) may have been encountered during EVA. (Skylab surface temperatures as high as 589°K (600°F) were observed in the area of the lost meteoroid shield but this was not an area of direct EVA.

Artificial Heat Sources

Temperature conditions are highly influenced by the size of the mass within the payload bay; the heat generated by the various electronics internal to the payload; and by the special heating requirements for sensitive equipment. However, none of these sources are as thermally prodigious as the Radioisotope Thermoelectric Generators (RTG's) presently being planned on several planetary missions.

Specifically, the U.S. Atomic Energy Commission (Space Nuclear Systems Division) has been actively pursuing a design of an RTG for the Mars/Jupiter/Saturn program. The data presented herein was based on a Multi-Hundred Watt RTG by GE.[1] The F-1 unit generating output power of 155 watts with an average fin temperature of 530°K (482°F) (heat source average temperature of 1330°K [1932°F]).

Assuming that this unit would fly on deep space missions, the output temperature must be dissipated by some type of heat rejection system until the RTG is deployed allowing the heat to radiate to space. EVA deployment using the astronaut appears to be feasible from the standpoint of radiation (discussed in another section) but direct handling presents EMU thermal design problems. One solution is to design to a lower EMU maximum temperature and provide handling aids for such special cases.

Summary

The temperatures given in Table 3-7 were used to select recommended design values for the EMU. Maximum (high) temperatures ranged from 228 to 483°K (-50 to 410°F) with a mean of 357°K standard deviation ~~93.5~~ 46°K (183°F, S.D. 83°F). Minimum (low) temperatures ranged from 128 to 290°K (-230 to 64°F) with a mean of 190°K, S.D. 49°K (117°F, S.D. 88°F). In comparing the value of the standard deviations to the EVA task temperature data, the selected temperature design points should be low: 140°K (-200°F), high: 395°K (250°F).

[1] Multi-Hundred Watt Radioisotope Thermoelectric Generator Program, LES 8/9 Program, MJS Program Bi-Monthly Progress Report (Jan.-Feb. 1975), by General Electric for the AEC, Space Nuclear Systems Division.

3.3.3 Durability - Crew Protection

Durability is defined as the wear and serviceability capabilities required of the suit while being worn by the crewman in performing payload-related activities in the orbiter bay and space environment.

The payloads will be numerous and highly specialized and will be representative of a large spectrum of disciplines. The duties of the EVA crewman to support these payloads may be extensive and diversified, and require exceptional activities in close proximity with all types and conditions of the payload hardware.

Durability or the resistance to wear becomes an important factor when one considers the large and varied number of tasks which may be performed by EVA in support of payloads. The real proof of durability lies in emperical data; however, estimates were made to obtain the required durability data.

In the development of these data techniques developed by Frank and Lillian Gilbreth were used in part. Fundamentally, the technique consists of (1) collecting and analyzing comparative data for the performance of various tasks, and (2) selecting and synthesizing the task data. The logic of this approach has been adapted by modern engineering and industrial practice and appears to be a practical method for our purposes.

The primary payload related source of wear is flexing which is a function of task performance. The wear rate is a function of crew suit time and of body and limb movements which become difficult to establish. Consequently, a numerical extrapolation method was used to determine EMU operating cycles.

A range of EVA tasks for supporting the baseline payloads were identified and are listed in Table 3-6. Body motions to perform each task were evaluated as to each of 10 mobility parameters as illustrated previously in Figures 3-2 and 3-5. The number of motion cycles times the number of performances of the task would equal the total number of cycles. Thus, where removal and stowage of contamination covers was calculated to occur 2234 times, two hip/waist flexion cycles were estimated: 2x2234 = 4468 cycles. Similar estimates were made for the entire matrix of tasks/motions. These estimates are considered to be conservative, and furthermore, do not include estimates of motion in preparation, translation, etc. Table 3-8 presents a summary of the results. Rather than present the total matrix of motions per tasks, an average for the 36 tasks is given. However, the sum of all the motion cycles times tasks are given.

The EMU design will be required to perform a variety of unique movements and it will be required to perform multiple repetitions of these movements. The primary flexing of the EMU occurs at the waist, shoulders, hips, and in the hand, wrist, and arm areas. Waist mobility is highly desirable to allow the astronaut to see around blocked areas during EVA as well as to perform tasks. The waist (hip and waist, side to side and rotation, and hip abduction) must be substantially designed to withstand continual flexing in this area, over 300K cycles in compound movements.

Other areas of substantial flexing are in the hips, shoulders, and knees. Again, compound movements may require over 300 K cycles for total performance in the "572 flight" schedule.

Table 3-8. EMU Flex Cycle Data

Type of Motion	Avg. No. Motions/Task	Total K-Cycles
Hip/waist flexion/extension	3.1	119
Waist mobility left/right	5.6	218
Elbow flexion/extension	0.5	21
Forearm mobility wrist rotation	4.3	166
Shoulder abduction/adduction	0.4	16
Shoulder lateral - median movement	2.9	111
Shoulder flexion/extension	1.7	67
Shoulder rotation down/up	3.2	124
Hip abduction leg straight	3.7	145
Knee flexion kneeling	0.4	16
Total number of performed tasks x payloads = 9066		

3.3.4 Dielectric Properties - Crew Protection

The dielectric property as used here is defined as the electrical property of material which in the event of physical contact with energized conductors has a resultant transmissibility characteristic of infinite resistance.

Electrical systems in the orbiter, the Spacelab, and free-flying spacecraft requiring crew interface during normal and contingency operations will be built to strict standards. These include the selection of electrical conductors which are non-flammable, or covered with non-flammable tubing or wire insulation capable of handling and operating deformations.[1] These requirements do not apply to material isolated by a container capable of retaining, within the container, any combustion resulting from high currents.

It is unlikely during normal trouble-free operations that the EMU would come into contact with the electrical configurations described above. Wire bundles and cables will be physically separate and isolated from flammable liquids and gases; in addition, pyrotechnic wires will be removed from normal function bundles to separate lines. If any problem should occur, it will most likely result during crew operating connectors, switches, and circuit breakers or during some unscheduled repair.

Operational procedures such as making or breaking connectors, and activating switches and circuit breakers will normally be performed with power off. However, this procedure may not be totally precluded. In the event that the power is not removed or cannot be removed, contact of electrically hot pins with the EMU must not occur such as to close the circuit. An example of such possibility could occur in the EVA task of installing solar panels on a spacecraft. It has been found that any amount of light striking a solar panel will generate current. Normally switches are not incorporated between the panels and the spacecraft buses to retain system reliability; therefore, solar panels are in effect electrically active at all times. EMU contacts across the solar panel connectors will be required not to short the panel. EVA repair of the Skylab microwave radiometer antenna involving interspersed power-on checks, is another example of potential shortings.

Static charge buildup in the EMU's metallic and non-metallic material components is another area requiring substantial consideration. It is important in that both the EVA astronaut and the payload electronics are susceptible to injury and possibly failure when a substantial voltage is applied to the subject matter.

The present maximum safe shock levels for dc and ac currents up to 2000 Hz are specified as 1.0 microampere applied internally and 100 microampere applied externally to the body.[2] The sensation produced by an electric shock depends on the current density at the point of contact with the source. It is the value and frequency of the current, its duration and pathway through the body that is mainly responsible for the damage.

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[1] JSC Design and Procedural Standard, JSCM-8080, No. 22 and 25

[2] JSC Design and Procedural Standard, JSCM-8080, No. 131

The data in Figure 3-14 are estimates of physiological thresholds taken from several studies[1] based on a 150-lb subject.

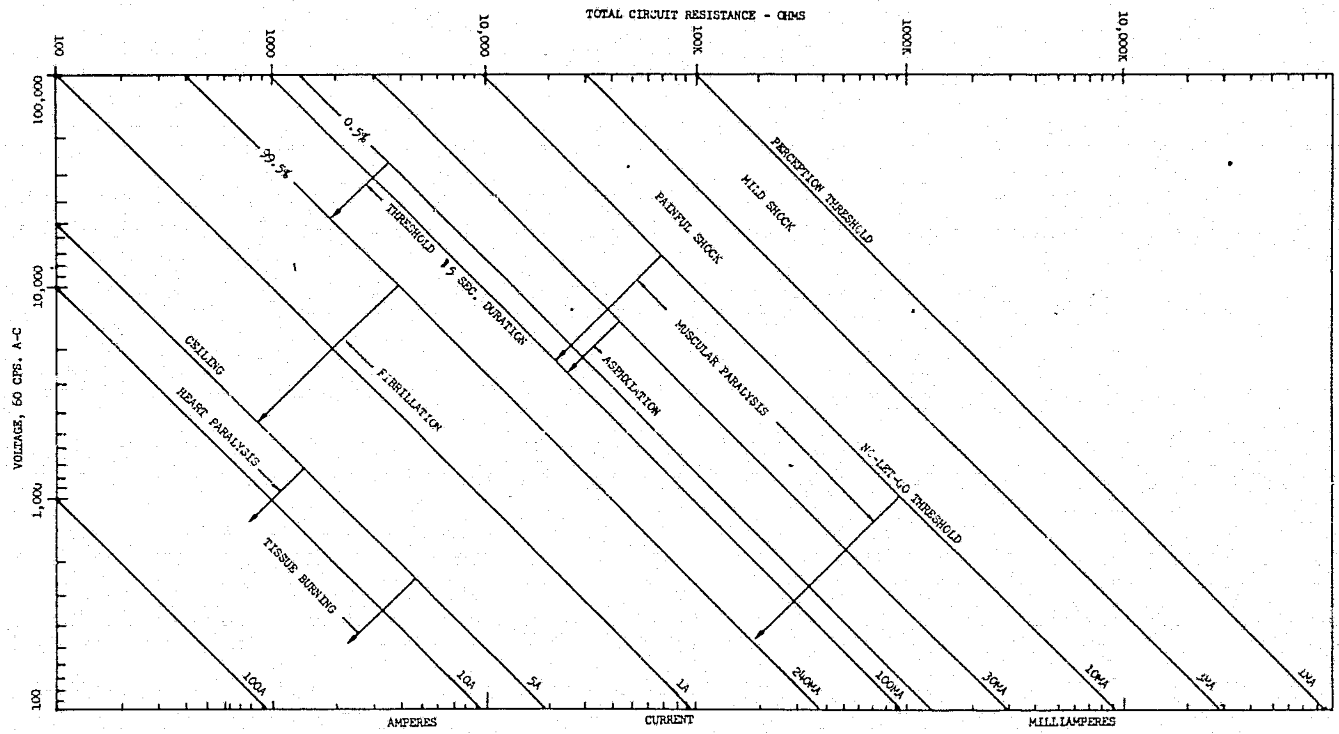


Figure 3-14. Range of Physiological Effect of 60 Cycle

Specific requirements cannot be stated other than in terms of crewman and payload protection; i.e.,

1. EMU materials and construction shall not be such that electrical potential or current from payload wiring, components, or static buildup could be painful nor injurious to EVA crewmen.

2. EMU materials and construction shall be non-conductive in those segments (e.g., forearms, chest) normally planned for interface with payload components which may be damaged by inadvertent shorting (dielectric test requirements).

3. EMU materials or design shall prevent static potential during payload operations so as to preclude spark discharge.

[1] Compendium of Human Responses to the Aerospace Environment, Vol. I, NASA CR-1205(1) prepared by Lovelace Foundation for Medical Education and Research, November 1968.

3.3.5 Radiation Resistance - Crew Protection

Radiation resistance is the ability of the EMU to protect the crewman from the natural radiation such as the Van Allen Radiation Belt in the South Atlantic anomaly and radioactivity such as the RTG in the Mariner Jupiter Orbiter (MJO) payload. This radiation protection will be required during the performance of EVA duties with and around the payloads in the orbiter payload bay and the surrounding space environment. It will be achieved through the selection of suit materials, suit design, and the possible addition of special auxiliary over garments as necessary.

The following tables (3-9 and 3-10) provide information with respect to radiation levels and dosage limits.

Table 3-9. National Academy of Sciences Recommended Dose Limits for Astronauts (Rads)

	Bone Marrow (5 cm depth)	Skin (0.1 mm depth)	Eyes (3 mm depth)	Testes (3 cm depth)
1 year daily average	0.2	0.6	0.3	0.1
30 days maximum	25.0	75.0	37.0	13.0
Quarterly maximum	35.0	105.0	52.0	18.0
Yearly maximum	75.0	225.0	112.0	38.0
Career maximum	400.0	1200.0	600.0	200.0

Table 3-10. Maximum Altitudes as Function of Shielding to Not Exceed Annual Radiation Doses

Orbit Inclination	Maximum Altitude (nmi)			Limiting Organ
	0 gm/cm^2	2 gm/cm^2	5 gm/cm^2	
29°	150	240	300	Eyes
60°	110	220	280	Eyes
90°	80	200	240	Eyes

The Radioisotope Thermoelectric Generator (RTG) system contains three thermoelectric generators. This system will be assembled to the payload prior to the payload being installed in the payload bay. The radiation levels of the generators in this configuration will be as indicated in Table 3-11.

Table 3-11. RTG Radiation Levels*

Distance From Source M	Typical Radiation Levels (mrad/hr)	
	F-2 RTG	MWH Pu-238
0.04	270	640
1.0	12	18
2.0	4	5
3.0	2	2

*These values are for one generator only. A side exposure of three generators would radiate three times the amount of radiation. An end exposure to three generators would radiate a higher level of radiation identified in the table for one generator, but a lesser level than that of a side exposure to three generators.

3.3.5.1 Induced Radiation Requirements Analysis

Upon installation of the payload in the payload bay, a cooling jacket and clam shell cover will be installed around the RTG generators. The exact composition and construction of the cooling system and jacket materials are undetermined at this time. However, the radiation intensities will be lower.

At the time of activation of the payload a planned EVA task is for the crewmen to op[illegible] clam shells and remove the cooling jackets, erect the payload and extend the RTG's. These tasks will require the crewmen to be in the immediate proximity of these items in order to unlatch the latching mechanisms, attach the manipulator arm, and accomplish the tasks as identified in Figure 3-15.

An evaluation of task time data from the "EVA" study indicates that the crewman would be working at about 3 meters from the RTG for about 12 to 15 minutes. This would be followed by a translation to the RTG and removal of the coolant jacket. The elapsed time before departing from the jacket would be about 20 minutes. Distances for most of this time would include:

Body	–	0.3 to ∿1.0 m
Eyes	–	0.3 to ∿1.0 m
Hands (skin)	–	0.04 to ∿0.5 m

About 12 additional minutes are required for translation and stowage of the coolant jacket at about 3 meters distance. Finally, about 15 minutes of crew tasks are performed around the spacecraft at distances of 1.5 meters or more. Total time within about 3 meters or less equals nearly one hour of crew time.

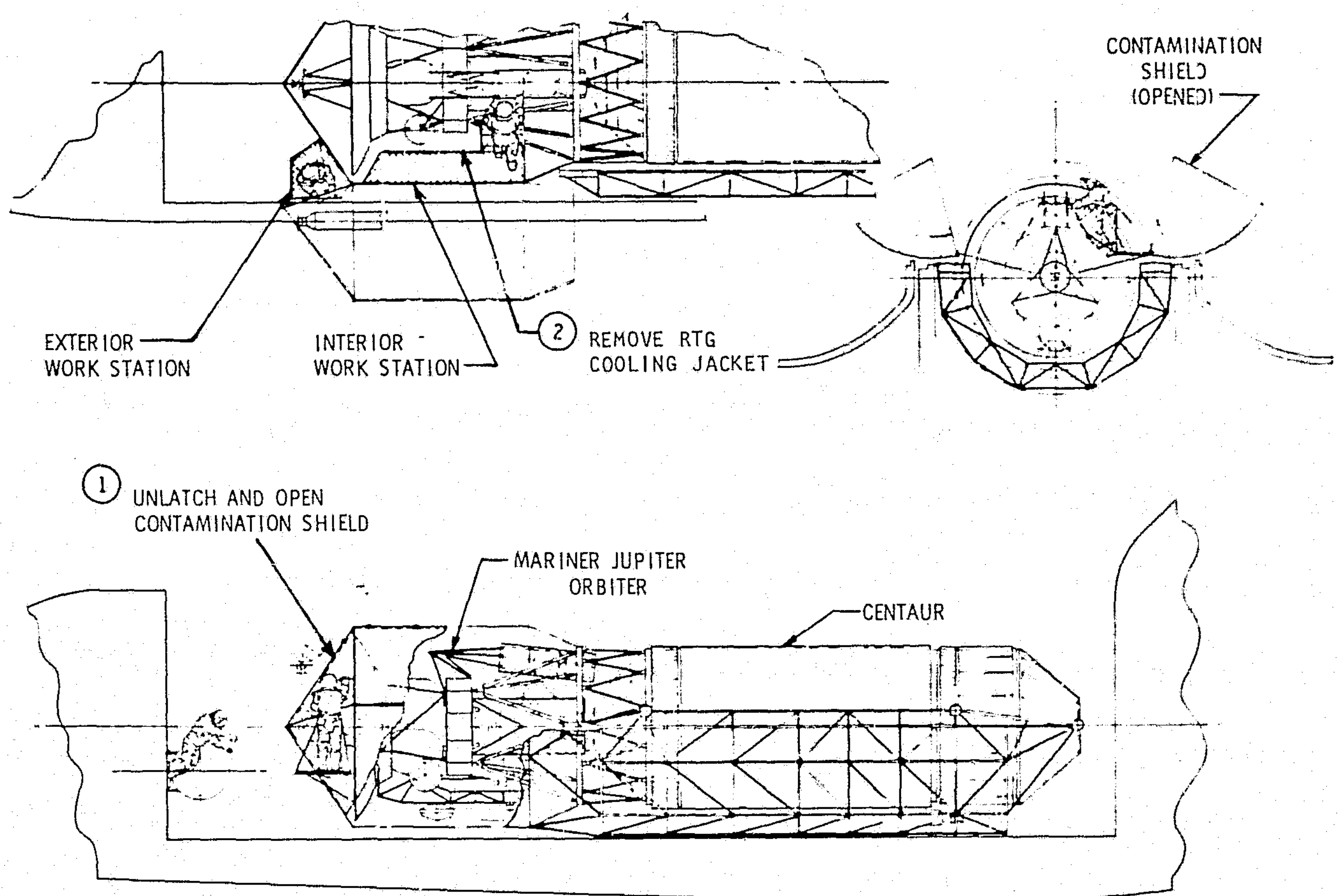


Figure 3-15. MJO Payload EVA Operations

Using a conservative approach, would indicate the potential exposure to the crewman:

	Dosage in MRADS	
	One MWH Pu-238	Three MWH Pu-238
Body	22	66
Eyes	25	75
Hands/forearms	122	366

Using the worst case (3 MWH units), the potential problem areas--eyes would receive about 1/4 allowable daily dose, while skin areas could receive up to 1/2 allowable daily dose. Figure 3-16 presents similar data in millirems. Since only about 20 payload deliveries in the payload model for 1980 through 1991 would be likely to utilize the RTG, there does not appear to be a major design requirement. However, since contingency reinstallation of the coolant jacket may be required, special purpose protective over gloves could be a consideration. Also, eye protection, especially in connection with the natural environment as discussed below may be a valid technology development.

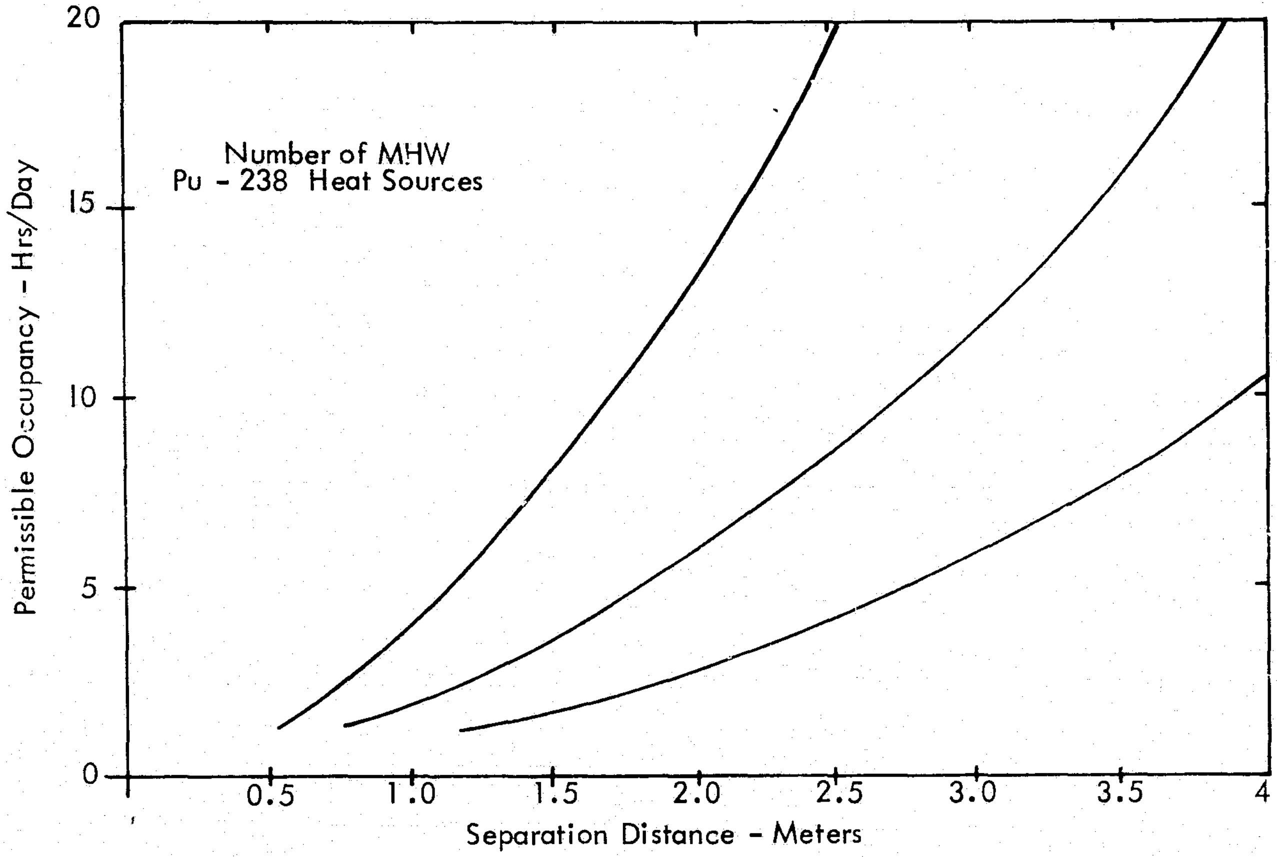


Figure 3-16. Permissible Astronaut Occupancy Periods for 150 MREM Day Limit

3.3.5.2 Van Allen Ionizing Radiation Exposure Analysis

To establish potential radiation protection from the South Atlantic anomaly, EVA task and mission operations data from the "EVA" study were examined. All missions in the study model were summarized as to EVA periods and durations, and orbit altitudes and inclinations were totaled. For simplification, missions were counted in one of 15 groups--three inclinations and five altitudes. Table 3-12 presents the mission distribution for all EVA missions.

Table 3-12. Summary Orbits/Altitudes with EVA

Nom. Alt. (km)	No. Flights With EVA, Nom. Inclination - Deg. 28.5	56	98
200	138	11	19
400	65	56	36
600	28	2	24
800	--	--	2
1000	--	--	1
Total	231	69	82

In consultation with Dr. James W. Haffner of Rockwell Space Division, the thresholds for protection from electron and proton particle energy were evaluated for an EMU shielding estimated at $\sim$0.3 gm/cm^2. At this level, the thresholds of concern would be $\sim$0.5 MeV of electrons and 15 MeV of protons as shown in Figure 3-17. Maps of the Van Allen belt flux were selected for $\geq$0.5 MeV electrons and $\geq$15 MeV protons for the five altitude levels given. Figures 3-18 and 3-19 respectively, illustrate proton and electron contours for flux density per square centimeter per second. Figure 3-19 also illustrates orbit traces of a 98-degree inclination WTR launch through northern and southern electron flux as well as the South Atlantic anomaly. Figure 3-20 shows typical ground traces from all three selected inclinations at a 600-km altitude.

Using Figure 3-19 as an example to illustrate the 24th through 31st revolutions, the worst exposure occurs on the descending node of revolutions 27, 28, and 29, at a flux density of up to 10^5 particles/cm^2/sec. Planned EVA for HEO missions indicates that the second available EVA period would start concurrently with the descending node of the 27th revolution (equator crossing) at a mission GET of 42 hours. In this specific case, the EVA crewman would be exposed to about 45 minutes at an electron flux level of 10^4 and about 40 minutes at 10^5 during a six-hour EVA.

Converting these to rads

$$3 \times 10^{-8} \times \mathrm{FLUX}_E = 3 \times 10^{-4} \ \frac{\text{rads}}{\text{sec}} \text{ for 45 min} = 0.81 \text{ rads}$$

$$= 3 \times 10^{-3} \ \frac{\text{rads}}{\text{sec}} \text{ for 40 min} = 7.20 \text{ rads}$$

The equivalent daily dose attributed to this one EVA period would be 8 rads due to electron flux only, at an equivalent of 0.3 gm/cm^2 for the EMU.

Using flux density maps for radiation at the specified particle energy, and for each selected altitude, EVA exposures were calculated for five altitudes and three inclinations as listed in Table 3-12.

The exposure data were calculated by taking mission event timelines and plotting planned 6-hour EVA periods as they could occur with respect to orbital traces for each of the 15 orbits. A summary of the results is presented in Table 3-13. It should be noted that selection of mission events, and consequently of EVA start and stop periods, was based on Shuttle reference missions. Therefore, it is a point evaluation neither optimized to avoid S.A.A. nor worst case. Consequently, variations plus or minus the indicated dosage could occur. However, the data do define levels of exposure which can realistically be encountered if EVA is routinely available for payload operations.

Examination of the data in the Table indicates that about 44 percent of the missions would expose the crewman to about 2 rads or less. However, to accomplish about 90 percent of the missions, the crewman could receive about 6 rads or less per 6-hour EVA or 18 rads during 3 EVA's. (While the nominal EVA duration was determined to be about 3 hours, a 6-hour EVA would

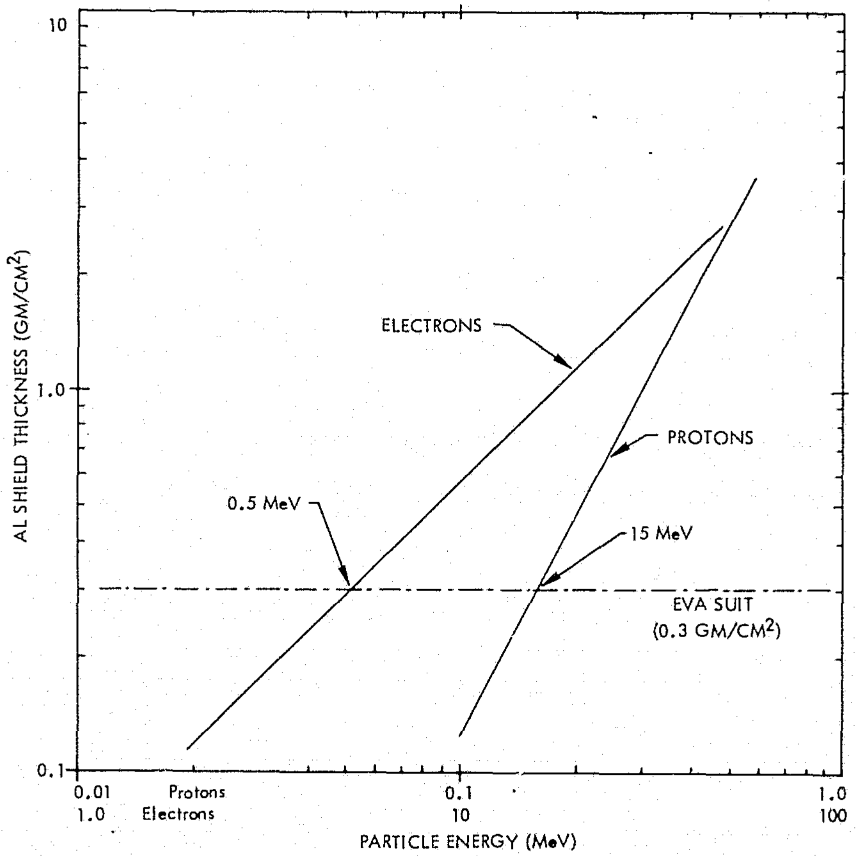


Figure 3-17. Particle Energy Shielding Requirements

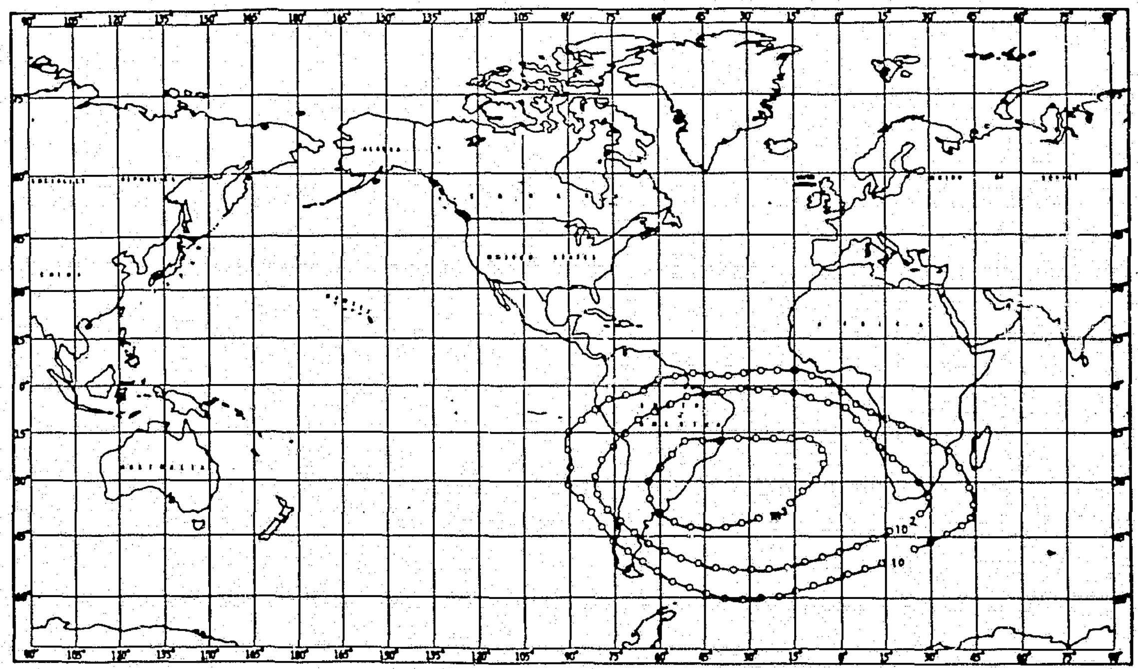


Figure 3-18. Proton Flux Densities at 600 KM

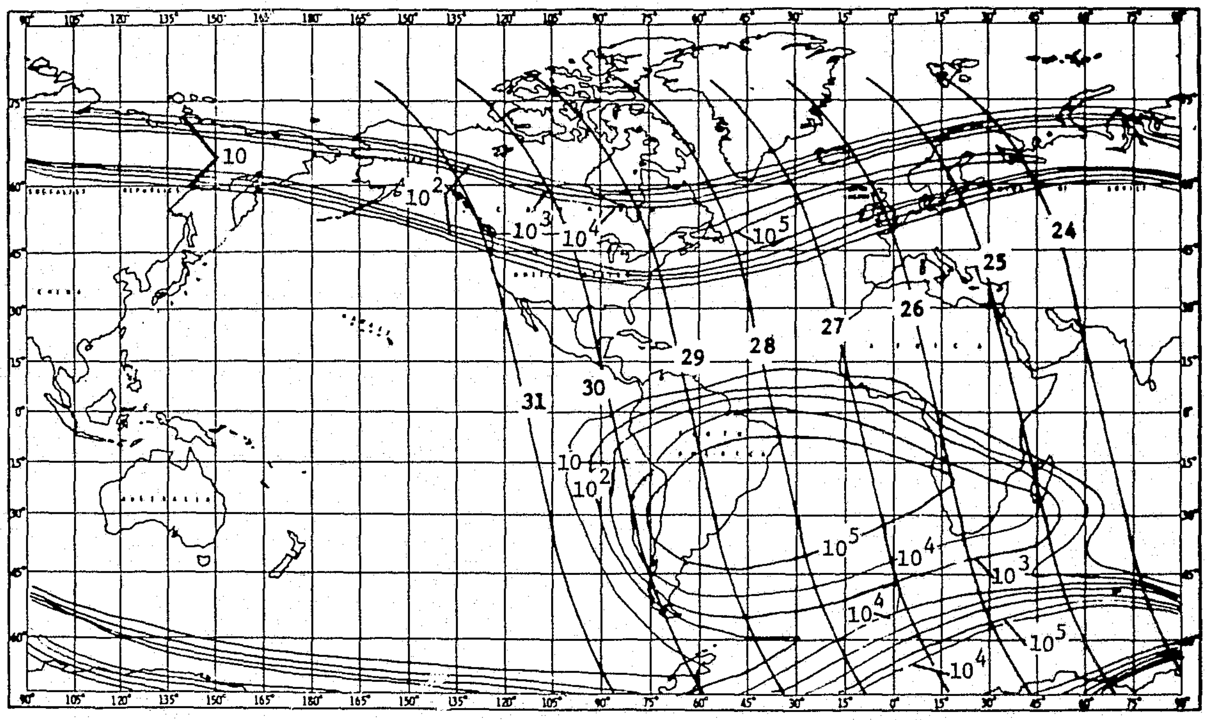


Figure 3-19. Electron Flux Densities at 600 KM (98 Deg. Incl. Ground Traces)

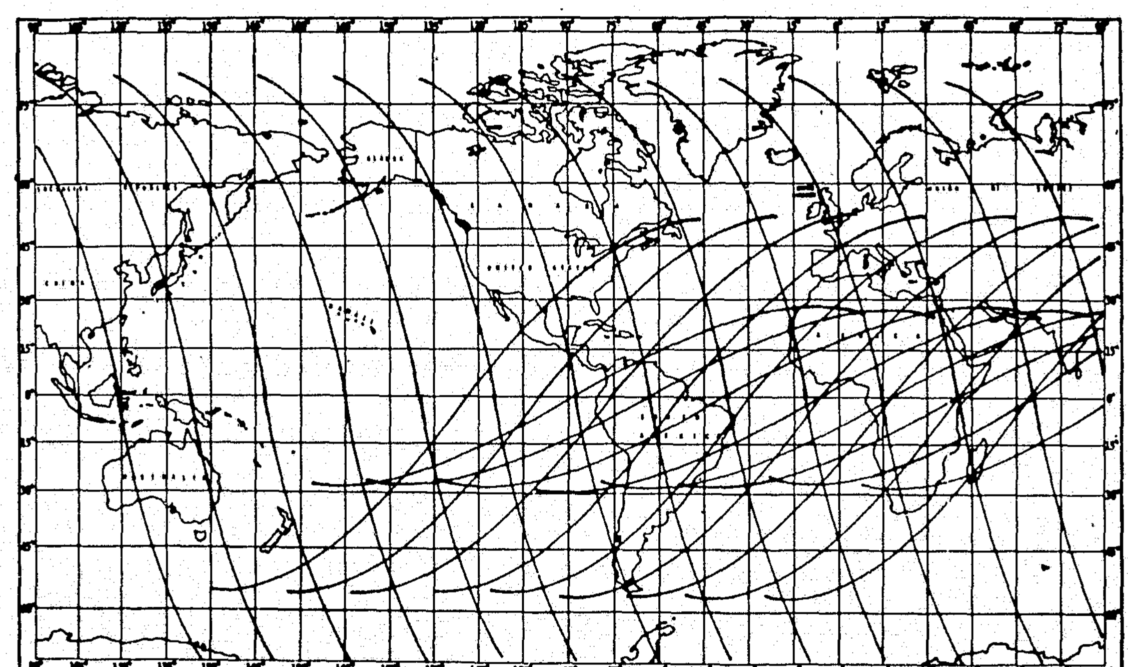


Figure 3-20. Ground Traces for 28.5, 56, and 98 Degree Inclinatious

C.2

represent a more conservative design value). By comparison, data from Skylab (50-degrees, 435 km orbit) were somewhat less - 3.6 rem/6-hrs of EVA for the worst dosage (3.6 rem ≅ 3.6 rad for primarily èlectron exposure).

Selecting a design-to-radiation dose is dependent on a variety of factors-number of flights per year or per quarter, exposures due to other operations than EVA, etc. Skylab information indicates about 0.1 rad/day or less for cabin radiation levels, or well within allowable levels. However, if EVA is not to be constrained by S.A.A. passage, it would appear that protection from dosages of 18 to 20 rads for multiple EVA's or 25 rads for single EVA's should be considered - about 1/3 the allowable 30-day dose.

To determine shield thickness required for improved radiation protection, refer to Figure 3-21. Taking a given radiation dose as unity, increased shield requirements can be calculated for allowable dose. Thus, for the example given, to reduce the 18.4 rads by one-half, first determine rads due to electrons and protons--in this case 18.3 and 0.06 respectively. Taking 18.3 as unity on the graph (1.0 radiation dose) 50 percent would be read at 0.5 of the dose, or, about 0.35 gm/cm^2. At this level, the dosage due to electrons would drop to 9.15 rads and due to protons 0.05 rads (i.e., 0.91 dose x proton dose rate).

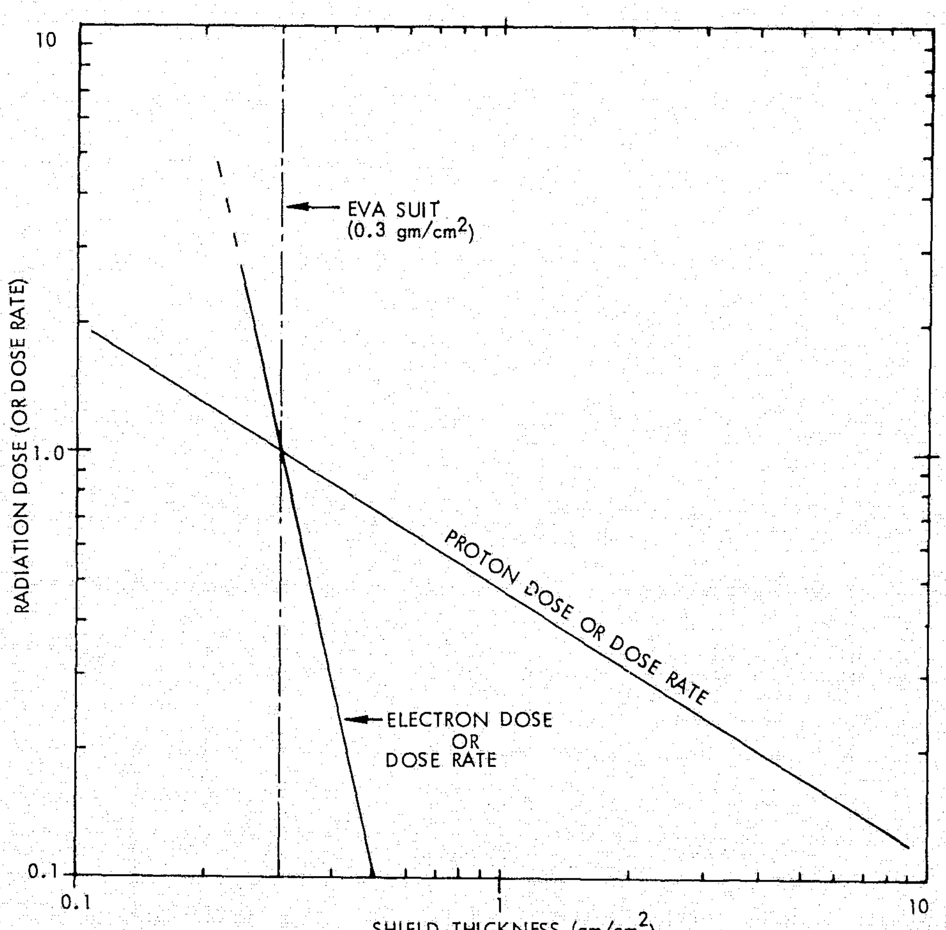


Figure 3-21. Shielding Thickness Requirements for Radiation Protection

Table 3.13 EVA Van Allen Exposure Data

Orbit Altitude	Protons				Electrons				Total Rads Per EVA
	Orbits Per Day	Nominal Flux 10^n	Avg. Hrs. Exposure 6 Hr-EVA	Rads	Orbits Per Day	Nominal Flux 10^n	Avg. Hrs. Exposure 6 Hr-EVA	Rads	
28.5 Deg									
200	5	2	0.31	0.06	8	4	0.60	0.55	0.61
400	8	2	0.16	0.02	9	5	0.87	6.10	6.12
600	11	3	1.09	1.22	15	5	2.18	21.38	22.60
800	-	-	-	-	-	-	-	-	-
1000	-	-	-	-	-	-	-	-	-
55 Deg									
200	3	2	0.28	0.05	16	4	0.87	0.70	0.75
400	8	2	0.42	0.13	16	4	0.42	5.19	5.32
600	10	3	0.57	0.56	16	5	1.72	10.62	11.18
800	-	-	-	-	-	-	-	-	-
1000	-	-	-	-	-	-	-	-	-
98 Deg									
200	5	2	0.25	0.05	16	4	1.39	2.05	2.10
400	8	2	0.29	0.06	16	4	0.33	4.56	4.62
600	10	2	1.04	1.00	16	4	3.29	4.66	5.66
800	15	3	0.57	0.76	16	5	1.94	11.95	12.71
1000	15	2	1.22	0.84	16	5	4.94	28.69	29.53

Similarly, selecting a shielding thickness of 0.4 gm/cm^2 would result in reduction to 28 percent of exposure due to electrons and 0.81 percent due to protons. For the case of 22.6 rads the result would be:

$$0.28 \times 21.38 = 5.99 \text{ rads}_E$$

$$0.81 \times 1.22 = \underline{0.99} \text{ rads}_P$$

$$6.88 \text{ total rads}$$

or about 30 percent of the original dosage.

The analysis shows that technology research is required to determine EMU shielding capabilities, and to perform further analyses of the required protection.

3.3.6 Penetration, Abrasion Resistance - Crew Protection

Penetration, abrasion resistance is defined to mean the ability of the external surface of the EMU suit to resist penetration or abrasions by physical contact with the surfaces of the payloads, payload bay, and associated structures and hardware while the crewman is performing his activities.

The sub-elements from which the suit design must provide penetration, abrasion resistance are: sharp edges, sharp corners, protrusions, fasteners (bolt heads, nuts, cotter keys, safety wires), plumbing, wiring, structures. Certain payload optics incorporate light baffles in their internal mechanisms which commonly have extremely sharp edges. If the optical shutters become jammed or inoperative, EVA might be employed to free them. This task could consist of reaching inside the barrel of the instrument past the sharp edges of the sun shields and manually freeing the shutters.

The EMU suit will be worn by the crewman while he is performing tasks both inside and outside of the payload bay relative to payload support activities. The crewman will be coming into physical contact with the structural surfaces of the payload bay and the payloads. The finishing processes of these contact surfaces will be governed by multi-organizational responsibilities. These responsibilities and the specific finish requirement specifications vary with organizational responsibility. On previous projects where EVA interface was limited to only a few spacecraft (Apollo CSM, LEM, OWS, or ATM) the approach selected was to require rounded or chamfered edges and corners, and to ensure that there were no exposed bolt threads, burrs, etc. With hundreds of spacecraft and sortie experiments being planned or developed, it might be more reasonable to ensure EMU protection against worst case situations. In evaluating various design criteria, Table 3-14 shows that significant differences may not exist between manned and unmanned spacecraft standards. The chart shows selected sources of design criteria from procuring agencies and contractors as they are likely to apply to payloads. The data suggest that EMU designs should tolerate at least the 0.038-cm radius (0.015-inch) for spacecraft as being the sharpest identified. While random burrs or screw heads are more difficult to define, a technology investigation of material resistance would appear to be indicated. This is especially important in view of the Skylab experience which indicates EVA may become necessary for a wide variety of structures and equipments. Glove protection for the crewman's fingers may be especially important in view of Skylab experience.

Table 3-14. Edge Radius Criteria

APPLICATION (EDGE AND IN-PLANE CORNER RADII)	EVA CRITERIA			STANDARD DESIGN CRITERIA		
	SPACECRAFT					
	JSC (1) *	MSFC (2)	EMU DESIGN (3)	OVERALL SHUTTLE (4)	CARGO BAY (5)	UNMANNED SPACECRAFT (6)
OPENINGS, PANELS, COVERS (CORNER RADII IN PLANE OF PANEL)	0.64 cm (0.25) 0.31 cm (0.13)	0.6 cm (0.23) or Guarded	0.025 cm (0.01)	0.97 cm (0.38)	0.64cm (0.25)	0.6 cm (0.25)
EXPOSED SHEET METAL EDGES, FLANGES, LATCHES, CONTROLS, HINGES, SMALL HARDWARE OPERATED BY THE PRESSURIZED GLOVED HAND	0.15 cm (0.06)	0.15 cm (0.06)	0.025 cm (0.01)	0.038 to 0.076 cm (0.015 to 0.03)	0.64cm (0.25)	0.038 to 0.076 cm (0.015 to 0.03)
SMALL PROTRUSIONS (LESS THAN APPROXIMATELY 0.48 cm (0.19)	0.15 cm (0.06)	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE

* NOTE: A 45° CHAMFER X 0.15 cm (0.06") (MINIMUM) WITH SMOOTH BROKEN EDGES IS ALSO ACCEPTABLE IN PLACE OF A CORNER RADIUS, THE WIDTH OF CHAMFER SHOULD BE SELECTED APPROX. THE RADIUS CORNER DESCRIBED ABOVE.

(1) JSC-10615-SHUTTLE EVA DESCRIPTION & DESIGN CRITERIA

(2) MSFC STD 512 - STANDARD MAN/SYSTEM DESIGN CRITERIA FOR MANNED ORBITING PAYLOADS

(3) EMU RFP

(4) ROCKWELL INTERNATIONAL SPEC. MA0103-304 - MACHINED PARTS-TOLERANCES

(5) GENERAL DYNAMICS/ASTRONAUTICS SPEC NO. 0-70902 - MANUFACTURING STANDARDS

(6) GPS, ROCKWELL INTERNATIONAL SPEC. MA0102-002, STANDARD DETAILS FOR METAL SHEET, PLATE, EXTRUSIONS, AND REINFORCED PLASTIC LAMINATES

3.3.7 Fluid Resistance - Crew Protection

Fluid resistance is the ability of the external material of the EMU to resist penetration or physical or chemical reactions when subject to contact or close proximity with fluids (liquids and gases) or chemicals.

Duties and activities related to and in support of the following payloads will require possible exposure of the crewman to the identified hazards:

Payload	Typical Fluids
Atmospherics, Magnetospherics and Plasmas in Space (AMPS)	GN_2, LN_2, N_2H_4 (Hydrazine), H_2O
Mariner Jupiter Orbiter (MJO)	GN_2, $MMH(CH_2NHNH2)N_2O_4$ N_2H_4 (Hydrazine)

The effects of these fluids on a suited crewman have been evaluated as follows.

H_2O - Water. Escaping H_2O would cause a film of ice or frost. The ice would reduce the mobility and flexibility of the suit. If the H_2O contacted the visor it would reduce the visibility. However, it is believed that the icing temperatures would not be low enough to permanently damage the existing state-of-the-art suit and visor material.

N_2O_4 - Nitrogen Tetroxide. This oxidizer is toxic and very reactive. While Apollo/Skylab materials would probably not have been affected by N_2O_4, any future EMU materials must be carefully evaluated.

N_2H_4 - Monopropellant Hydrazine. This fuel is toxic, flammable, and caustic. It is unsuitable for use with various materials; therefore, EMU selection must be carefully evaluated.

CH_2NHNH_2/N_2H_4 - Monomethyl Hydrazine/Hydrazine. This fuel is toxic, volatile, and reactive with CO_2 and O_2. Suit damage may occur. Droplets could have a wetting effect on the visor which would cause temporary reduced vision.

LN_2/GN_2 - Liquid Nitrogen/Nitrogen. A large rupture or rapid escape of GN2 could cause a rapid temperature lowering to as much as 144°K (-200°F) (if equipment was already at a comparatively low temperature). LN_2 boiling point is 78°K (-321°F). These temperatures could cause brittleness and cracking of the suit material due to differential contraction.

Crewman activities in support of the above-identified elements will require development. Testing of suit materials under exposure to the above identified elements is recommended to establish the selection of the required suit materials.

3.3.8 Impact Resistance - Crew Protection

Impact resistance is the ability of the EMU, suit, helmet, and life support system, to resist intentional and non-intentional rapid applications of force against sharp objects.

The normal usage of the EMU does not plan for intentional impact; however, some force applications may be required with the gloved hand. Whether a gloved hand is used to apply a sharp force or a tool held by the EVA astronaut, impact forces traversing either through the arm or the suit should not be allowed to cause damage to any portion of the suit. This is critical to mechanical joints, couplings (glove to arm), and the portable life support system.

Unintentional impact presents a problem during translation or movement made in a direction outside the field of vision. The EMU is substantially more bulky than normal clothing and as a result it becomes difficult to precisely position one's self to pass through tight areas. Movement through the orbiter bay is not anticipated to be rapid; therefore, impact upon flat surfaces most likely will not cause damage to the EMU. Impact upon sharp surfaces, such as corners and edges, can become a serious factor due to the single point of force concentration on the EMU.

The more critical areas will require some protection from impact of any type. The joint areas having moving parts (i.e., shoulder, elbow, knee) will require protection from permanent deformation which will result in restriction of movement. The torso frontal area most likely will not need special protection since that area is within the astronaut's field of forward vision. The portable life support unit if mounted on the astronaut's back will most likely be subjected to the greatest number of encounters, with the helmet also being subject to impact in some cases.

Estimates of crew translation rates are in the order of 1 to 1.5 meters per second ($\sim$3 to $\sim$5 feet per second). Considering the mass of the suited crewman, forces in the order of 2224 N (500 lb) could be expected. If an exposed corner were encountered, with a radius of about 0.64 cm (0.25 in.), the pressure could reach 5500 N/cm^2 (8000 psi).

3.3.9 Bio Contamination - Crew Protection

Biological contamination is any form of living matter that may attach to the EMU threatening crew health. In addition to the crewmen, and the orbiter environment, the most probable sources of such contamination will be the various biological experiment payloads mounted in modules within the orbiter or cargo bay. The Space Processing discipline has a number of biological investigations mounted in separate modules. Life sciences modules contain various organisms with the potential for bio-contamination. All of these units will have their own environmental control system; however, it is anticipated that some module gas leakage will occur. Bio contaminates such as bacteria and other micro-organisms appproach the size of particulates and may escape from the pressurized modules along with gas leakage.

These microorganisms are relatively hardy and seem to survive wide variations in conditions. In the proper environment they have the ability to rapidly reproduce. Therefore, should an EMU attract any microorganism and bring them back into the orbiter environment, rapid reproduction could take place. In any environment a number of microorganisms will exist; for example, clean air 2.8 to 28/cm^3 (1 to 10/cu ft), stratosphere $\sim$2 to 0.0^2/cm^3 (<1 to 10^{-3}/cu ft), human skin 1.35 to 13.5 E05/m^2 (1 to 10 E04/sq in.).

Microbiological samples from Skylab indicate significant buildup and distribution of certain organisms. In particular, the EMU was found to have mycological samples, with visible fungal growth on a liquid cooling garment.

Introduction of pathogenic microorganisms which may have a deleterious effect on the flight crew will require the EMU to be resistant to such contamination. The EMU RFP has established requirements for control of bacteria and fungus growth, and defined suit drying as a control over bacteria. In addition, material selection may be a necessary requirement or an alternative to various external control techniques. Since the actual amount of biological contamination is difficult to predict due to the unknown types and quantity that might adhere to the EMU, further research and laboratory tests appears to be in order.

3.3.10 Crew Reaction Time - Crew Performance

Crew reaction time is limited to EVA preparation (i.e., the donning and doffing of the EMU for normal EVA operations, scheduled and non-scheduled maintenance, and for contingencies) and includes suit-up time, prebreathing time, and airlock operations.

Crew reaction time is highly dependent upon the operating pressure within the EMU. Several pressure levels have been considered in the past and for future space flight. The Apollo A7L series operated at 26×10^3 N/m^2 (3.7 psi), from a cabin pressure of 34×10^3 N/m^2 (5 psi). The current Shuttle orbiter baseline plans are to provide an EMU at 28×10^3 N/m^2 (4 psi). Since the orbiter cabin is pressurized to 100×10^3 N/m^2 (14.7 psi) (sea level), the use of suits at these low pressures requires a period of time to be set aside for de-nitrogenization of the EVA astronauts. Any egress into space via an EMU operating below 55×10^3 N/m^2 (8 psi) will bring on the condition often referred to as the "bends".

Figure 3-22 compares the preparation time requirements between an 8 psi and a 3.7 psi spacesuit, prior to egress from the orbiter airlock and entry to the orbiter payload bay. The use of the 8 psi suit is estimated conservatively to require about 1.5 hours of preparation time compared with approximately 3.5 hours for the lower pressure garment for routine operations. The major influencing factor is that of the oxygen prebreathing required for approximately 2 hours prior to EVA equipment preparation, suit donning, final equipment checkout, and the airlock operations. It should be noted that certain other crew activities can be performed during the early prebreathing period by use of portable oxygen masks.

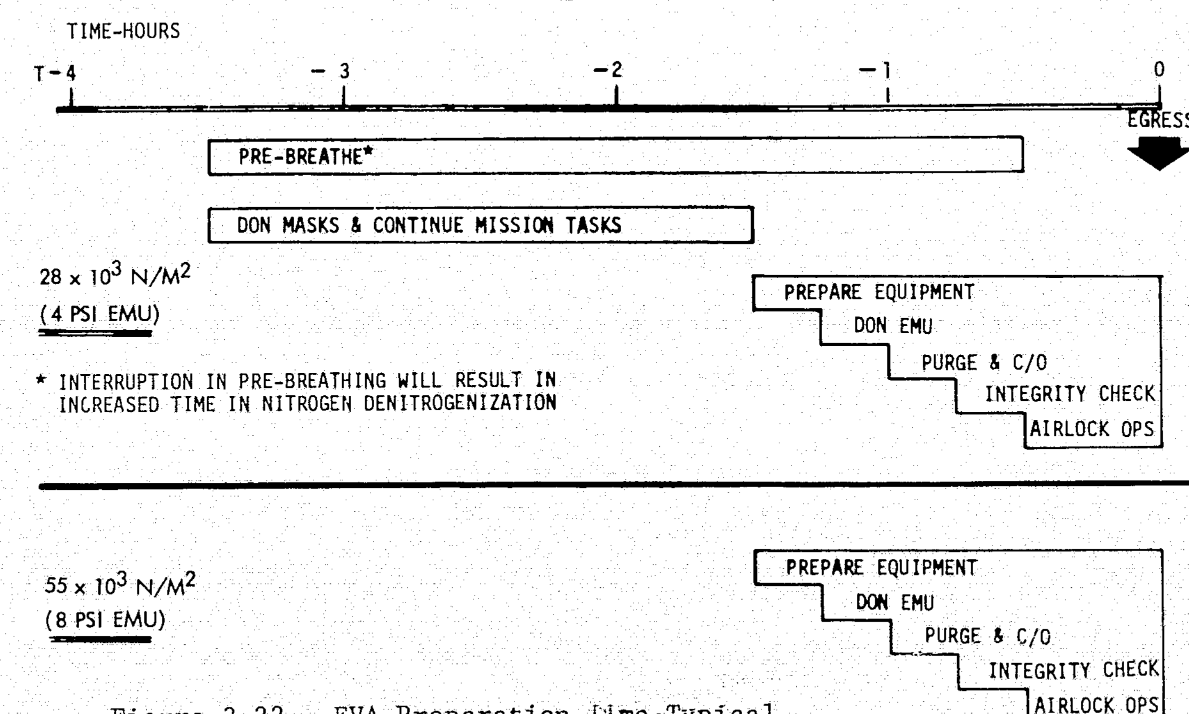


Figure 3-22. EVA Preparation Time-Typical Routine Timelines

Results of previous studies indicate that operation at 8 psia will improve operations and/or substantial cost savings could be attributed to quick reaction; e.g., increased experiment time in an EVA mode.

It appears that a rapid reaction time could best be used in support of time-critical contingencies. In the referenced "EVA" study, historical data concerning failures were analyzed. Table 3-15 summarizes time critical consequences with respect to those systems that are affected and which could potentially be corrected within a degrading time period.

Table 3-15. Matrix of Time-Critical Consequences

AFFECTED SYSTEMS	PROBLEMS	TIME CRITICAL CONSEQUENCES: LOSS OF CONSUM	LOSS OF SPECIMEN	LAUNCH WINDOW	GND/TRK TARGET	THERMAL CONDITION
FLUID SYSTEMS	FLUIDS LOSS	√	√	√	√	√
STRUCTURES & MECHANICS	KINEMATICS FAILURE	—	√	√	√	√
ELECTRICAL SYSTEM	OFF-NOMINAL	√	√	√	√	√
CONTROLS & DISPLAYS	FAILED INDICATORS/ CONTROL	—	—	√	√	—
INTERFACES	DEPLOYMENT, ENGAGEMENT/ DISENGAGEMENT	—	√	√	√	√

Based on the number of anomalies analyzed from historical data which resulted in time-critical consequences, percentages of total payload deliveries were calculated and applied to Shuttle payloads. A screening of the Shuttle payloads was made so that the percentage would only be applied to those payloads with a potential for the defined time-critical consequence (i.e., only payloads with biospecimens could have a potential loss of specimens). Further screening eliminated, where feasible, anomalies where EVA response was precluded (i.e., automated spacecraft "missed targets" will only occur during autonomous operations). Other categories were considered on the basis of occurring anytime during a mission. Thus, for the automated spacecraft which might suffer loss of consumables, only a small percentage may occur during the delivery phase where EVA response is possible. The sum of all time-critical anomalies is about 15 percent of the total calculated number of potential anomalies.

The results are listed in Table 3-16. The numbers on the row labeled PRC data are based on examination of the historical source. Thus, 26 percent of the spacecraft were determined to have suffered loss of consumables due to anomalies. Since 255 automated spacecraft and 230 sortie payloads in the traffic model require fluid consumables, it was predicted that 26 percent (or 122 total) of the traffic model payloads could exhibit the same failure. These numbers are entered on the line labeled "NASA" under the heading "Equivalent Payload". DoD and Non-NASA Sortie Equivalent Payloads were calculated on the basis of the number of flights only since payload details were not available.

Table 3-16. Potential Payload Time-Critical Anomalies

TYPE OF DATA	LOSS OF CONSUM-ABLES	LOSS OF SPECIMENS	MISSED LAUNCH WINDOW	MISSED TARGET	THERMAL ANOMALY	TOTAL BASE
PRC DATA						
NO. ANOMALIES	22	8	75	144	27	525
RATE/86 PL'S	0.26	0.09	0.87	1.67	0.31	6.1
SHUTTLE DATA						
NO. POSSIBLE PAYLOADS						
NASA AUTO S/C	255	24	152	-	255	261
NASA SORTIE	230	39	-	36	181	235
TOTAL	485	63	152	36	436	496
EQUIV PAYLOAD						
NASA	122	6	132	60	135	3026
DOD	39	0	78	-	47	-
NON-NASA SORTIE	10	1	-	6	9	-

Only a qualitative evaluation can be made relative to the requirement for a 8 psi suit versus 4 psi. The 8 psi suit could improve operational efficiency and reaction time by elimination of prebreathing, and potentially improve crew operations by reduced prebreathing requirements. Crew safety may be enhanced, both due to increased protection from bends if a more rapid EVA contingency response became necessary, and by providing a greater margin in time and partial pressure of O_2 if EMU pressure drop should occur. Current technology developments for a 8 psi system are projected to equal or exceed mobility capability of previous technology 5 psi systems. Other considerations include technology risk and development costs in comparison to the baseline Shuttle EMU. Comparative cost analyses are required for 8 psi qualification versus cost benefits from reduced EVA response time.

3.3.11 External Interface - Crew Performance

External interfaces as defined here refer to auxiliary devices, load bearing points and provisions for attachment of tools to the EMU, all of which enhance EVA crew performance.

It is anticipated that the EMU will be required to provide additional interfacing beyond that of providing a livable environment for the EVA astronaut. The ideal design of an EMU would be to keep it as simple as possible and free from any functional requirements other than to provide the proper environment. However, the astronaut will be required to move about the orbiter bay and the payload equipment. During the EVA he must prepare equipment and deploy or assist in the deployment of mechanical devices. In most cases, the payloads will be designed such as not to require the assistance of special tools. However, during normal maintenance and contingency operations it is highly probable that various types of mechanical aids will be required. A problem may occur while the astronaut is translating about the bay with tools or a tool kit. The problem is multiplied when multiple tools are required to be used interchangeably. It is impractical to return each tool to a kit, and the tool cannot be allowed to float in space. One solution is to attach the tool(s) via lanyard(s) to appropriate loops conveniently located about the EMU. Either the interface must be sufficiently reinforced or the attachment must breakaway such that a mass of 5.7 kg (12.5 lbm) (i.e., astronaut in an EMU) moving about catching the tool will not damage the EMU.

In addition to the above requirement the EVA astronaut is required to be firmly restrained to be able to react forces. Several methods or combination of methods may be used. He may require that only his feet be secured or he may require the aid of waist lanyards or a combination of these. In the past foot cleats have been used as have "Dutch shoe" platforms. There are a substantial number of tasks which require only his feet be secured while performing these tasks; however, provisions should be made for additional load bearing points for force reaction.

Some consideration has been given to providing a built-in capability in the EMU to accept various tools and also to integrate a universal tool as part of the suit. A review of the various payload requirements quickly eliminated the integrated suit/tool requirement while the built-in capability to accept various tools appears to have merit but it also adds complexity and constraints which are undesirable in a universal EMU. The major difficulty lies in the payload definition and requirements which in many cases have yet to be defined to a point of confirming requirements. Also, providing a dedicated portion of the suit to a specific or general interface with a tool will generally limit the EMU as opposed to making it more versatile.

It is expected that many payloads in certain configurations are so closely packaged that the EVA astronaut moving about will be required to push about at various points on the EMU. These various areas of force application will require that the EMU be capable to accept these forces without permanent deformation or damage and in any event, shall not endanger the EVA astronaut.

Evaluation of EVA tasks shows that reactions of force application occur most frequently with the knees, shoes, waist, and gloves. Without question, the gloves will receive considerable use in the area of force application consisting of pushing, sequeezing and torquing forces. Based on previous EVA's the majority of tasks will also involve a foot restraint. The shoulders, elbows, and knees will in all cases be subjected to a direct pushing force.

An evaluation was conducted of various EVA tasks where the EMU may expect greater than normal pressures to be exerted upon it. These are summarized in Table 3-17. Figure 3-23 depicts the various tasks from "EVA" study design concepts.

Table 3-17. EMU Estimated Contact Forces and Locations

Figure No. 3-22	Task Type	Point of Force Application	Force N (lbs)
A	Antenna Replacement	Waist Attachment*	178 (40)
B	Antenna Deployment	Waist Attachment	160 (36)
C	Unlock Boost Latches	Gloved Hand*	110 (25)
D	Sensor Boom Placement	Gloved Hand & Foot Attachment	150 (34)
D	Electrical Umbilical Disconnect	Gloves & Knees	160 (36)
D	Payload Booster Propellant Line Disconnect	Gloves & Knees	125 (28)
E	Solar Panel Installation	Waist Front*	178 (40)
F	Payload Boost Cover Removal	Front of Knees	160 (36)
G	5-M Tubular Boom Installation	Shoulders*	110 (25)
H	Sunshade (Flat-Type) Deployment	Knees (Front/Back), Shins*	60 (13)
I	Sunshade (Circular) Deployment	Waist & foot attachment	80 (18)
J	Sensor Cover Removal (Subsatellite)	Lower Leg Front (Shins) & Front Breast Area*	20 (5)
K	Large Antenna Deployment via Multiple-Tube Booms	Elbows, Knees (Front), Waist Front*	150 (30)
L	Instrument Pointing System Attachment	Waist, Knees (Front), Gloves	80 (18)
M	Large Antenna Swingout Deployment	Back of Knee*	200 (45)
		* Also foot restraint	

3.3.12 Mobility - Crew Performance

For this application the terms "mobility", "flexibility", "dexterity", and "wearability" are all closely related and all equate to the degree of ease (freedom of action), and efficiency that the suit allows the crewman to perform his payload support activities.

"Flexibility" relates to the element of suit pliability, and the stiffness of the suit materials. "Mobility" relates to the same general criteria but denotes the additional ability to shift or move from one position to another, and the amounts of crewman torque or effort required to overcome pressurization factors. "Dexterity" more specifically relates to the ease and efficiency which the glove allows for the accomplishment of manual tasks with the least amount of restricted or lost motion during the performance of the task. "Wearability" relates to the elements of fit and comfort of the suit to the crewman. The wearability element becomes increasingly more important as the payload crewman activities become more extensive, complicated, and of longer durations.

Based on an evaluation of payload operations the EMU shall be designed to provide for bending and centers of rotation of the mobility joints to closely approximate the natural body joint movements. This shall include the shoulder, waist, hip, knee, ankle, elbow, wrist, and hand systems which allow the crewman freedom of movement in the pressurized modes. The total EMU system design shall permit the crewman to maintain a natural body position and a variety of work positions without excessive force and to perform complex mobility functions.

Various payload requirements for mobility are illustrated in Figure 3-23.

Glove Dexterity. The space suit EV gloves have been defined in the Shuttle EMU RFP as requiring emphasis in the following areas:

- Hand protection from the extreme thermal conditions in space
- Crewman capability to wear pressurized gloves for periods of 7 hours without discomfort
- Crewman capability to grasp tools, handholds, and similar interfaces for extended periods (5 minutes) without fatigue
- Providing complete freedom from pressure points on the hand
- Elimination of material bulk and location of seams for improved dexterity

No additional payload-derived requirements were identified in this study. Emphasis to glove mobility importance resulted from Skylab operations and astronaut reports on limitations imposed by their EV gloves.

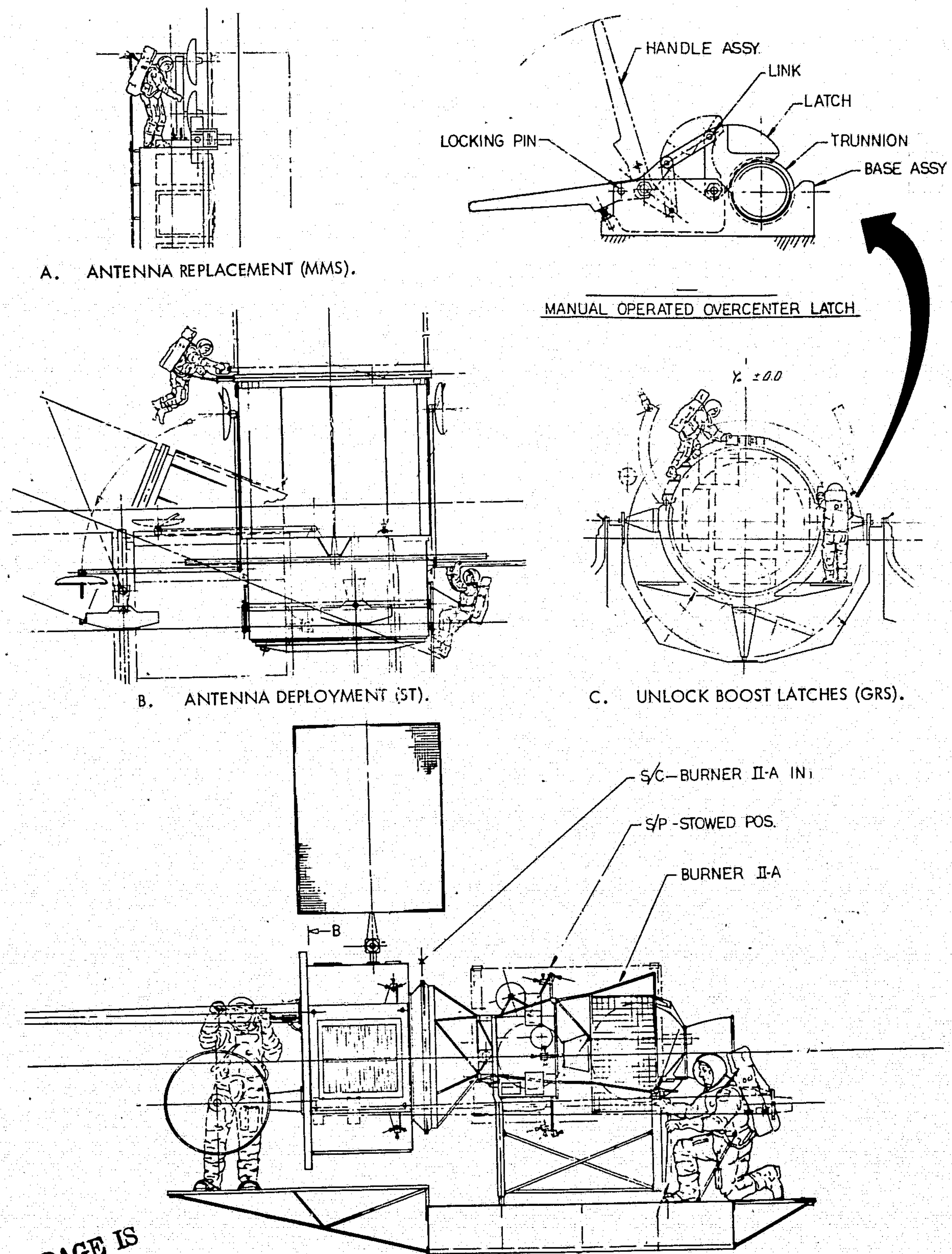
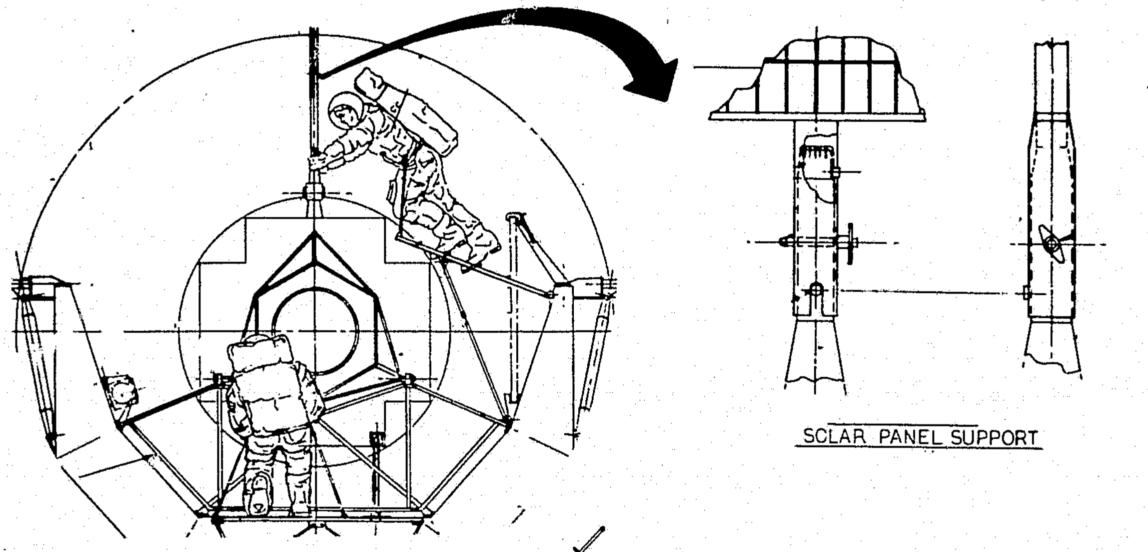
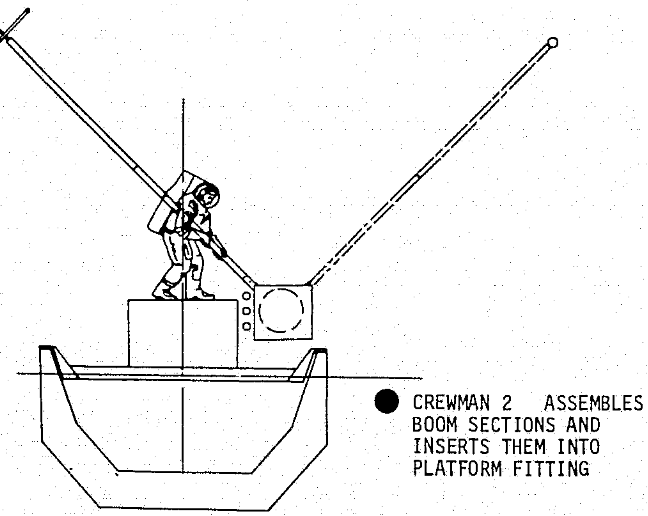


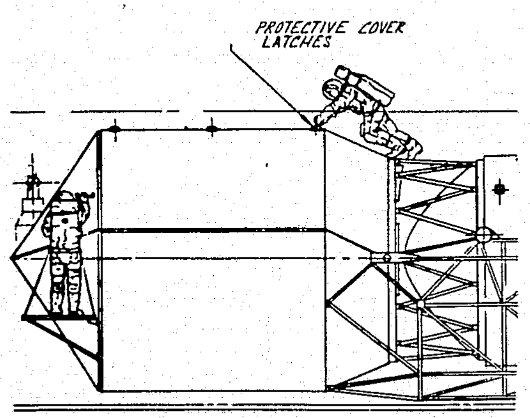
Figure 3-23. Mobility - Crew Performance (1 of 3)



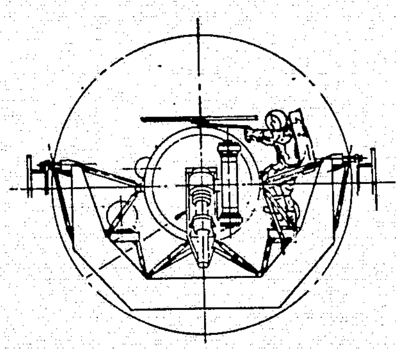
E. SOLAR ARRAY INSTALLATION (MFM).



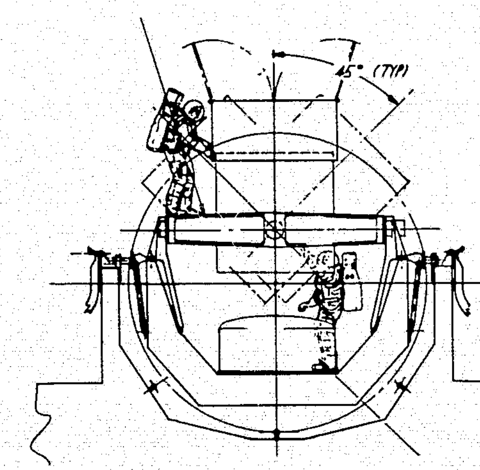
G. 5-METER BOOM INSTALLATION (AMPS).



F. BOOST PROTECTIVE COVER LATCHES UNLATCHED (MJO).

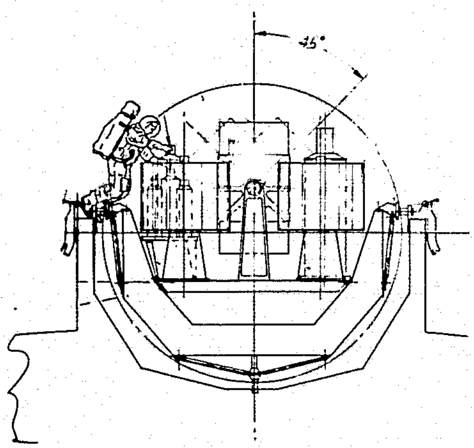


H. FLAT SUNSHADE DEPLOYMENT (SIRTF).

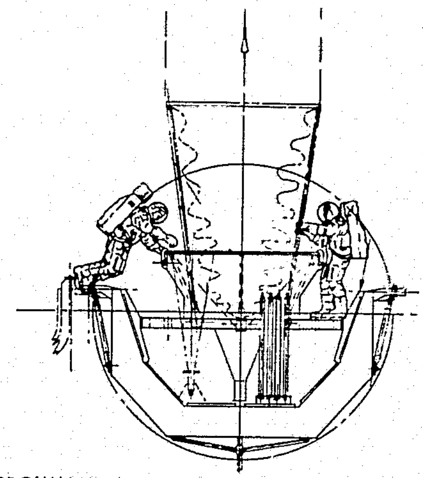


I. CIRCULAR SUNSHADE DEPLOYMENT (AMPS).

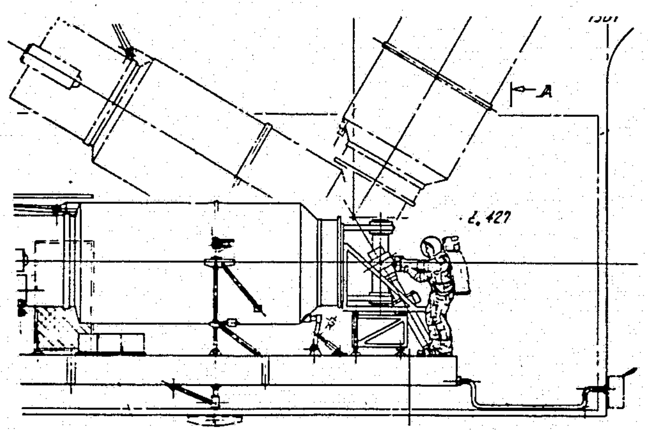
Figure 3-23. Mobility - Crew Performance (2 of 3)



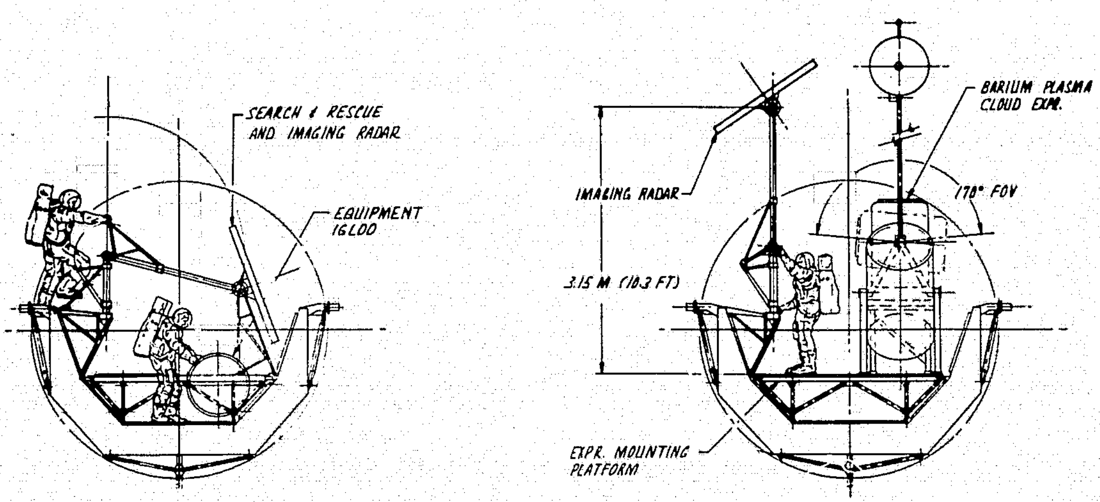
J. SUBSATELLITE SENSOR COVER REMOVAL (AMPS).



K. MICROWAVE RADIOMETER ANTENNA DEPLOYMENT (ATL).



L. INSTRUMENT POINTING SUBSYSTEM (IPS) ATTACHMENT (SIRTF).



M. SIDE-LOOKING RADAR DEPLOYMENT (ATL).

Figure 3-23. Mobility - Crew Performance (3 of 3)

3.3.13 Visibility/Orientation -- Crew Performance

Visibility/orientation is the ability of the EMU helmet to provide the crewman with adequate powers of observation and orientation to allow him to perform his payload support activities in and around the payload bay. The following characteristics are applicable to the optical characteristics of the EMU helmet: (1) head mobility, (2) window size and viewing angle of helmet, and (3) optical characteristics of visor assembly.

The payloads will be numerous and diversified. The related crewman support functions will also be numerous, extensive, and complicated, and may require functional and calibration adjustments. These activities will require precise and delicate EMU optical visibility and orientation. The payload support functions may be accomplished by individual crewman activities or with crewmen working in combinations with each other. In addition to the above identified payload support requirements and crewman activities, it will be necessary for the crewmen to be able to visually observe the progress of each other at various distances during the performance of related activities.

The surfaces of the payloads (and the orbiter) will have various types of finishes including white paint and anodized aluminum. It will be necessary for the visor to provide crewman protection from light intensities reflected from these surfaces as follows:

Material	Reflectance
Cargo bay liner, teflon impregnated glass fabric	85 to 90%
ST and other payloads, S13G white paint	85%
ST outer coating - silver-coated teflon	95%
Orbiter radiators	90% (96 to 100% specular)

Of additional concern is the crewman's ability to evaluate his body position and equipment with respect to the payload. A particular problem may relate to body orientation with respect to the life support backpack. Although current design concepts are for a unit smaller than Apollo, the crewman has little or no visibility of the assembly, and must rely on a sense of its bulk. Supporting research should be employed to determine the scope of the problem. and potential design solutions such as "cat whiskers" or relocation of life support components to more visible areas, etc. It is recommended that simulations be conducted in a backpack mode, and, if orientation problems are encountered, that packaging design and location (e.g., to front or side areas) be investigated. Skylab data have indicated problems of body orientation, especially in viewing the feet during EVA's.

Shuttle EMU RFP requirements provide optical characteristics definition which appears to be adequate for all payload/EVA tasks identified in this study in regard to helmet optical requirements; therefore, viewing with respect to body orientation is the pertinent requirements area.

3.3.14 Communications--Crew Performance

Communications relates to the capability of the crewmen to be able to communicate with the orbiter and for each crewman to be able to communicate with each other while performing EVA tasks.

The extravehicular communications system (EVCS) is planned to provide communication and EKG telemetry capability. The hardline capability will be voice only and is provided by EMU umbilical connection to the PLSS during pre- and post-EVA operations.

During the operational phases certain instruments such as the side looking radar in the ATL payload will be radiating high level energy. This system will have a nominal power level of 50 to 100 watts (5 kw peak) in the X-band (3 cm wavelength). The transmission will be IF. If EVA activity is to be accomplished during the operational cycle of the side looking radar, it will be necessary to incorporate two IF-type band stop filters into the EMU communications system to prevent blockage or saturation of the EMU communications.

Certain orbiter systems such as the rendezvous radar system will radiate sufficient energy during its operational cycle to block or saturate the EMU communications system. This system has a 2-degree beam width and will radiate at an average power level of 40 watts in the Ku-band (2 cm wavelength). The signal level will be in the order of 200 milliwatts and will emanate in all directions. If EVA activity is to be accomplished during the operation of this system, it will be necessary to provide the EMU communications system with the following special protection to prevent blockage or saturation of the EMU communications:

1. A "true trap" filter to absorb external RF energy transmission

2. Special shielding to the EMU amplifier circuits to suppress stray pick up

Structural signal masking or blockage due to working in and around payloads would be minimal in wavelengths of 3 to 20 cm. However signal masking or blockage could be expected in wavelengths of 25 to 50 cm.

3.3.15 Operating Time - Crew Performance

Operating time refers to the amount of time an EVA astronaut is required to be suited and performing EVA tasks.

EMU operating time is generally not related to the suit capability but rather is a function of payload tasks. Estimates for planned EVA operations such as preparation of payloads for operation, general maintenance, and preparation of payloads for entry, have been well within the present state-of-the-art capability. For example, several of the lunar exploration missions exceeded 7 hours, similarly Skylab EVA's were over 6 hours in some instances. A review of Shuttle payloads indicates that a minority could require EVA in excess of 8 hours (viz. Space Telescope), or alternatively, these payloads can be satisfied by multiple shorter duration EVA periods. Figure 3-24 presents a graphical summary of mission EVA times from the previous "EVA" study. The purpose of the chart is to show that all EVA's can be performed under 6 hours. These times range from about 1.8 hours as a low to just under 6 hours for maximum EVA time. The majority of EVA's, 62 percent will be less than 2.7 hours. A more questionable area is that of contingency EVA.

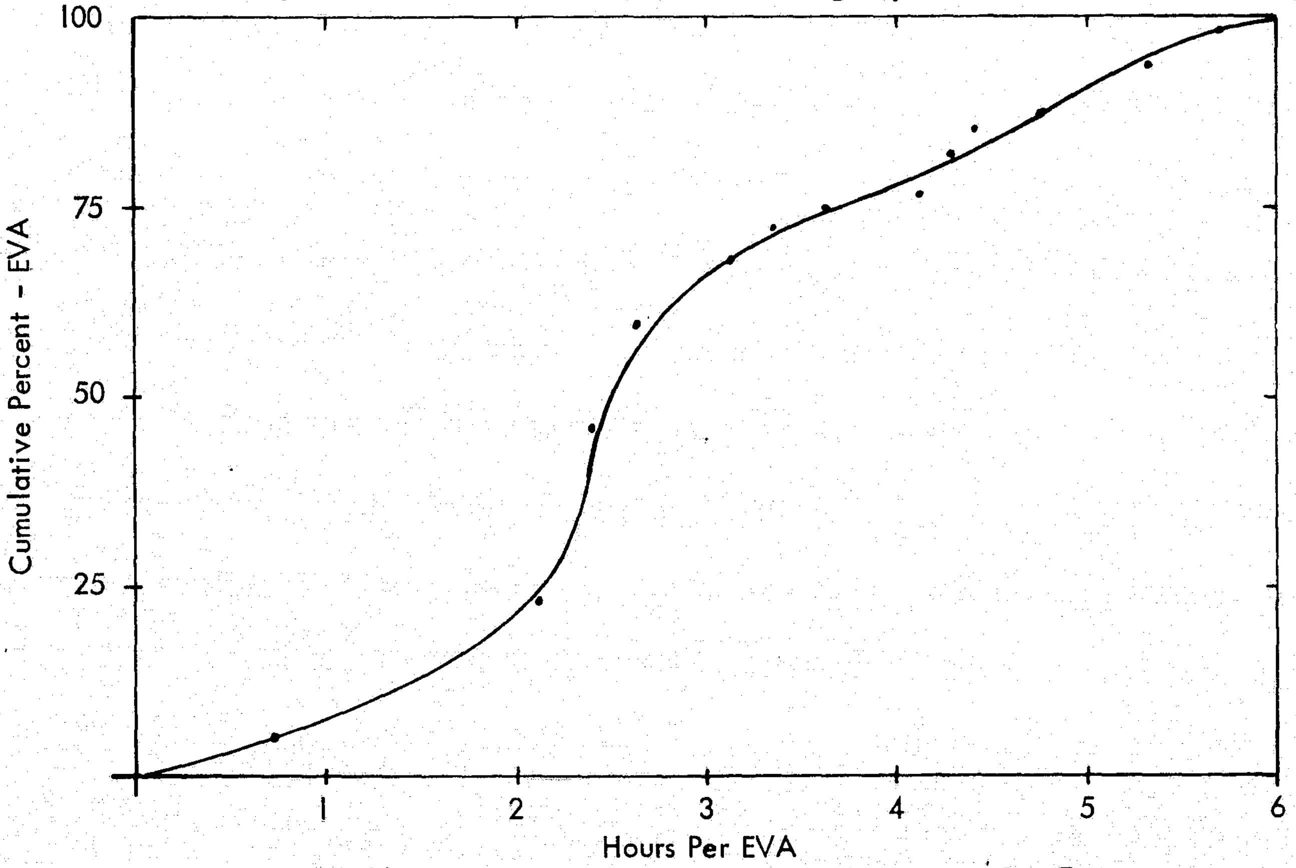


Figure 3-24. EVA Operating Hours Per Egress vs. Cum Percent

Contingency activity is, without a doubt, the most difficult to assess. By definition a continency is a failure mode which, if not checked or corrected, may degrade or preclude mission success. There are little or no data available pertaining to any contingency analyses on the presently planned missions. Two pertinent sources are a Planning Research Corporation report[1] and the Skylab program. Some typical anomalies taken from the above referenced sources which are applicable to Shuttle missions are:

Fluid system leakage
Contamination cover partial deployment
Erection mechanism jamming
Unclean separation

[1] Reliability Data from In-Flight Spacecraft, 1958-1970, PRC R-1453, dated November 30, 1971.

Umbilical separation failure
Lack of positive indication of a function
Stem device failure
TV camera control loss
Appendage deployment failure
Stuck valves and motor drives

Repair time for these failures now becomes dependent upon the criticality of the failure, the extent to which a repair will be attempted, and the ability to get to the failure. With regard to criticality of the failure, the astronaut can attempt to repair a payload, neutralize it for return to ground, or assist in jettisoning it. The attempt to repair will depend upon the philosophy of on-orbit maintenance/repair.

Consumption of time most likely will be dependent upon the ability of the astronaut to get to the failure. Where substantial disassembly is required to get to a minor failure, it may require far more total (continuous) suit time then past experience has shown. Actual Skylab data show that 27 mission objective tasks and 12 in-flight repair tasks were added to the previously planned EVA operations. Table 3-18 lists these tasks and their actual elapsed times. All of these times are within the projected 6-hour capability; however, it can be postulated that in the interest of economics in the Shuttle era, it would be most desirable to effect all repairs to a deployed spacecraft on one launch and preclude the cost of a second Shuttle flight. Thus, for the failure effects of the Skylab launch, if a subsequent Shuttle flight were to have an EVA repair activity added to it, both the solar array deployment and thermal protective cover tasks would be required. While this activity could be performed on more than one day, it would be more attractive if the demands on the orbiter time could be minimized so as to allow it to complete previously scheduled activities. In this case, the two task times could add up to >6 hours of EVA.

This is a very subjective area and dependent upon the payload design. Consequently, this requirement to increase suit operating time beyond 6 to 7 hours per day should be held in abeyance until the payload design, maintenance and repair philosophies, and more realistic failure modes are defined. However, it is recommended that EMU requirements should consider capability to extend or add to an EVA to accomplish up to 8 hours by use of kits, recharge, or perhaps modular exchange of life support units.

3.3.16 Reliability/Maintainability - Crew Performance

Reliability is defined as the ability of the EMU suit system to adequately provide the crewman with the capability of performing his tasks and functions throughout a required time duration and quantity of functional operations without deterioration of its operating and support characteristics beyond acceptable limits.

In addition to providing the crewman the capability of performing the tasks of unlatching the retaining latches and locks, uncovering optics and sensors, and erecting booms and antennas, the EMU suit must possess the reliability to provide the crewman with the support and capability to retract all the applicable booms and antennas, and relatch all latches and locks, and cover all optics and sensors that were initially uncovered.

Table 3-18. Skylab Unscheduled (or Contingency) EVA Tasks/Times

Task	No. Times Performed	Task Time Hrs:Min
Attempt to deploy solar array	1	00:32
Deploy solar array	1	03:03
Changeout EUV spectroheliograph film	1	00:15
Pin X-Ray telescope door open	1	00:05
Repair battery charger regulator module	1	00:07
Clean white light coronograph occulting disk	2	00:05
Attach piece of sail material	1	00:05
Deploy twin-pole sunshade	1	03:58
Remove UV spectroheliometer aperature door ramp	1	00:20
Install particle collection unit	3	00:20
Attach two parasol material samples	1	00:06
Install six-pack gyro cable	1	00:37
Remove dual X-ray telescopes aperature door ramp	1	00:18
Remove EUV spectroheliograph aperature door ramp	1	00:21
Retrieve particle collection unit	2	00:14
Retrieve parasol material sample	2	00:06
Perform coronograph atmospheric measurements	2	00:23 00:51
Attach cosmic ray detector	1	00:02
Pin H-alpha 2 aperature door open	1	00:04
Retrieve disk and strip samples	1	00:06

Task	No. Times Performed	Task Time Hrs:Min
Attach sunshade material samples	1	00:09
Attach thermal control coating samples	1	00:32
Repair pitch axis of microwave radiometer antenna	1	3:35
Perform X-Ray/UV solar photography	3	00:53 00:37
Perform comet sighting & corongraph photography	2	00:48 00:31
Change out four film packs	1	00:38
Pin EUV spectroheliograph door open	1	00:01
Perform electronographic camera comet observations	2	01:06 01:32
Repair X-Ray telescope filter wheel	1	01:35
Retrieve sail material	1	00:03
Retrieve meteoroid cover sample	2	00:04 00:08
Measure X-ray/UV housing temperature	2	00:04 00:09
Take DAC photographs	1	00:41
Retrieve zero-g fixture cover	1	00:03
Take Nikon photographs	1	00:22
Retrieve cosmic ray detector	1	00:08
Retrieve thermal control coating samples	1	00:06
Retrieve twin-pole sunshade samples	1	00:06
Extend ATM center boom	1	00:01

The EMU suit must also provide the availability of the crewman to override, stow/jettison, any automated mechanism or operation which incorporates an EMU performance requirement. The reliability of the EVA system must be equal to the reliability of the automated system it is designed to replace.

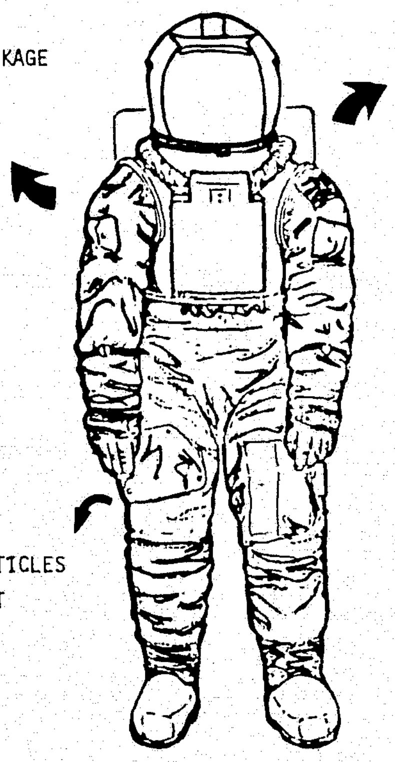
Maintainability is defined as the ability or characteristics of the EMU suit to be maintained in a satisfactory condition to continue its required crewman support capability. The design and construction of the EMU suit and its components shall ensure ease and rapidity of repair and maintenance in the field and during mission use. The design shall be such that the use of special tools shall be minimized for normal maintenance and checkout of the EMU.

3.3.17 Contamination - Payload Protection

Contamination in this instance equates to the contribution or production of foreign materials (gases, liquids, solids, and particulates) through the processes of leakage, venting, and out-gassing of the EMU. Contamination sources and levels identified for the A7L suit are identified in Figure 3-25. They are shown as representative of existing state-of-the-art suit contamination characteristics, including particulates, water vapor, and gases. Payload requirements relative to these contaminants are discussed below.

CURRENT TECHNOLOGY (A7L)

- PARTICLES (DUST, LINT, METAL)
  0.5 - 500 MICRONS
- H_2O VAPOR
  1.72 LB/HR (0.22 gm/SEC)
- GASES LEAKAGE
  0.01634 LB/HR (0.0022 gm/SEC)
- ORGANICS (TRACE GASES)
  9.5×10^{-6} LB/HR (11×10^{-7} gm/SEC)



CONTROL TECHNIQUES/ADVANCED TECHNOLOGY

- REAR DIRECTED H_2O VENTING
- COVER GARMENT - LEAKAGE PROTECTION
- HEAT SINK - NO H_2O SUBLIMATION
- O_2 REGENERATIVE SYSTEM - LOW GAS VENTING

Figure 3-25. Contamination Sources - EVA Equipment

3.3.17.1 Particulate Requirements

Payloads utilizing optics to accomplish their objectives are sensitive to contaminants which could collect on the lens surfaces. Payloads which have been designed to measure space environment would be adversely affected by artificial contamination. Table 3-19 indicates the specified cleanliness levels of the study representative payloads.

Table 3-19. Cleanliness Levels for Representative Payloads

Payload	Cleanliness Levels	
	Oper. External	Non-Oper. External
a. MMS	10,000	10,000
b. ST	1,000	10,000
c. ATL	100,000	100,000
d. AMPS	100,000	100,000 (unpress)
e. MJO	1,000	1,000
f. SIRTF	1,000	5,000
g. ASP	1,000	5,000

The following Table 3-20 identifies the applicable cleanliness classes and allowable numbers and particle sizes in microns relative to the above identified cleanliness levels.

Table 3-20. Cleanliness Classes Definition

Class	Allowable Number & Size of Particles	
	0.5 Microns & Larger	5.0 Microns & Larger
1,000	1,000	Not applicable
5,000	5,000	30
10,000	10,000	65
100,000	100,000	700

Astronomical payloads are particularly sensitive in terms of "artificial stars" or small particles. For sortie astronomy payloads the contamination cloud is defined[1] as requiring particle sizes less than $\sim 10\mu$ for IR telescopes or 0.1μ for UV or optical spectra.

[1] "Astronomy Working Group Recommended Contamination Limits for Astronomy Sortie Missions", GDCA-DDA-73-009, dated 11 June 1973, revised 31 October, 1973, Prepared by Convair Aerospace Division of General Dynamics, Contract NAS8-29462.

3.3.17.2 Condensation

Condensation is required not to cause one percent or greater absorption of radiation. Ice particles of 1μ size must be less than 10^{-2} gm/sec (0.08 lb/hr). An analysis made of IR cooled telescopes by Dr. F. Witteborn of ARC[1] is quoted as follows:

"A rough estimate can be made of the amount of water that will condense onto the mirror of the cooled (20°K) infrared telescope during an EVA by considering the spacesuit as a point source of water molecules at a distance of 1 meter from the front of the telescope. The source strength (water molecule discharge rate) is 1.72 lb/hour (7.2 x 10^{21} molecules/sec). The telescope is assumed to be 4 meters long from entrance to primary mirror, so that the mirror is 5 meters from the source. A sticking coefficient of unity is assumed throughout, so that the fraction of molecules absorbed by the mirror is determined only by its solid angle. 1.8 x 10^{19} molecules per second strike the mirror, so that a 0.1 micron layer is built up in roughly 2 minutes. A 0.1 micron layer raises the emissivity in the IR by 0.01 (with modest wavelength dependence)which is the total allowed for the entire mission without noticeable degradation of performance.

"The actual geometry is improved by the fact that the water sublimator is on the astronaut's back which would be pointed away from the telescope if he were to work near the entrance aperture. Of course, he must not turn his back towards the entrance aperture unless its door is closed. It is also clear that any work he does near the entrance aperture must be accomplished in less than 2 minutes unless some other protective device is used inside the telescope.

"The above discussion did not take account of the degradation of the cold baffles near the entrance aperture of the telescope. These would accumulate deposits nearly 25 times as fast as the primary mirror. Deposits on the baffles might degrade their off-axis rejection capabilities. Of even greater concern is the responsibility that dust from the EVA suit would stick to the baffles or mirror surface. Again the off-axis rejection would suffer resulting in more background noise.

"It may be necessary to continually purge the telescope barrel with a non-condensable gas such as helium in order to prevent condensation of ambient atmospheric gases (e.g., atomic oxygen, nitrogen). Sufficient pressure would be maintained to provide a mean free path for collisions of 10 to 50 cm. This purge gas would also provide protection against the water vapor released by the EVA suit.

"The use of an EVA near an unprotected IR telescope is certainly not expected in its normal operation. The use of a molecular-water-venting sublimator during such an EVA does not appear to present insurmountable problems. This conclusion does not hold if the water is vented in liquid or crystalline form."

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[1] NASA-ARC Internal Latter SSA:246-6, dated 1/11/74 to Dr. Lubert Leger (ES5), JSC from Dr. F. Witteborn. Subject: Contamination of Cooled Telescope Mirror by Water From EVA Suit Sublimator.

3.3.17.3 Column Density - Contaminant Cloud

Astronomy payloads require that absorption lines be optically thin with gas densities less than $10^{12}/cm^2$. The EMU, as defined above, would be a negligible contributor.

3.3.18 EMI/EMC - Payload Protection

Electromagnetic interference (EMI) is the interference caused by the electromagnetic fields generated by the operation of electronic units or the transmission of electrical or signal energy which causes conflict to another electronic system/subsystem which is operating in close proximity.

A system can be either EMI radiating (radiating EMI through its operation which can cause interference with another electronic system) or EMI susceptible (itself being affected by the EMI generated by another electronic system).

All electrical systems of the EMU must comply with Specification SL-E-0001 (which is a special adaptation of MIL-E-60510 for Electromagnetic Compatibility Requirements for the Systems for the Space Shuttle Program) during all phases of the Shuttle mission. The EMU electrical systems will be designed to meet the requirements of Specification SL-E-0002 (which is a special adaptation of MIL-STD-461A for Electromagnetic Interference Characteristics Requirements for Equipment for the Space Shuttle Program). However, these requirements are not necessarily compatible with payload designs. The Spacelab ICD requirements reflect both the JSC SL-E-0002 specification and MIL-B-5087B, as well as an extensive listing of unique requirements which may or may not be compatible with the EMU. A typical DoD spacecraft (GPS) specifies five MIL standards or documents, plus two SAMSO documents--all with their own unique requirements. A more thorough review of all potential payload EMI/EMC requirements is essential to ensure payload, orbiter, EMU compatibility.

Items of concern for possible EMI causes of degradation to the EMU suit EKG telemetry capability are:

a. Solenoids
b. Circuit breakers
c. Motors
d. Motor-driven latches
e. Transmitters

3.3.19 Dielectric Properties - Payload Protection

The use of the term dielectric property here is defined as in paragraph 3.3.4; i.e., the electrical property of material which in the event of physical contact with energized conductors has a resultant transmissibility characteristic of infinite resistance.

Electrical systems in the orbiter, the Spacelab, and free-flying spacecraft requiring crew interface during normal and contingency operations can be damaged if the EMU should come into contact with connectors, switches, and circuit breakers as during some unscheduled repair. Concern for payload equipment as well as for the crewman indicates that the same requirements apply as described in paragraph 3.3.4.

3.3.20 Surface Damage - Payload Protection

In performing various payload-related tasks, the EVA crewman is a potential source of damage to various payload elements. Various factors may influence this potential, such as visibility, discussed previously, which may result in accidental damage, or force application. A review of payload characteristics and discussions with the payload community indicates:

1. Structural elements are not elements of concern.

2. Preferred work station attachments, however, should be on pallet or orbiter structure.

3. Various thermal coatings are more sensitive, as discussed below.

No specific data are available on thermal degradation due to handling. However, as an example of sensitivity, the teflon-coated glass cloth of the cargo bay liner will degrade from a solar absorptivity (α_S) of 0.33 to 0.45 with about 1400 hours of UV exposure only. However, less than 25 percent of this degradation (α_S = 0.36) is the maximum allowable.

No clear requirements can be derived relative to the protection of the payload. Figure 3-26 illustrates typical sensitive elements on the payload, including thermal coatings and solar panels.

The following generalized requirements should be considered in the design and fabrication of the EMU.

1. Ensure crewman mobility to maneuver about payload areas.

2. Provide visibility in the direction of crew movement at all times.

3. Minimize bulk in non-visible EMU equipment areas.

4. Pad, or otherwise protect hard elements of the EMU.

Of particular concern are various payload thermal coatings. Damage to the thermal protection can degrade the thermal properties of the spacecraft thus affecting its performance. Typical finishes of concern are:

1. $\bar{Z}93$ paint - chips easily, absorbs oils, 1.3 E-06 to 1.9 E-06 meters (50 to 70 millionths of one inch) degrades reflectance

2. S13G paint - fairly rugged but can be cut, can become soiled but is washable

3. Aluminized thin coatings - subject to removal by abrasion

4. Reinforced kapton - is tear resistant but can be damaged.

5. Teflon coated glass cloth - can be ripped

6. Silver-coated teflon - reflectance degrades quickly with surface damage

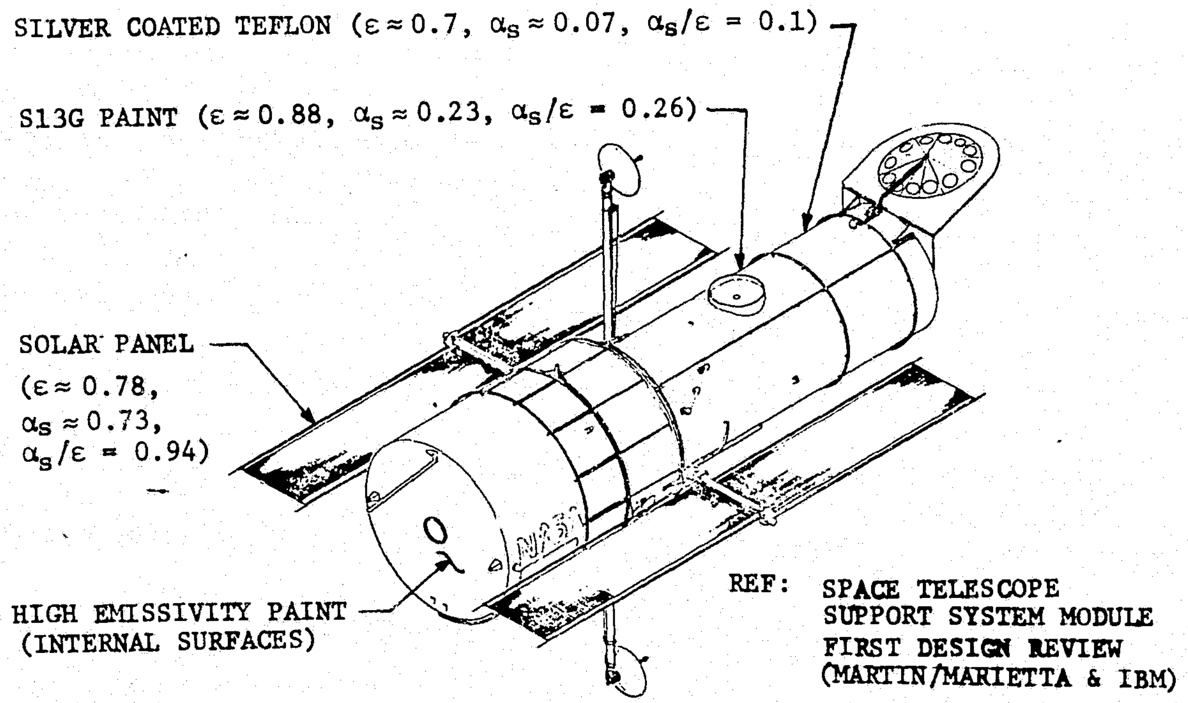

Figure 3-26. Typical Spacecraft Thermal Finishes

SECTION IV. CONCLUSIONS AND RECOMMENDATIONS AND EVALUATION OF REQUIREMENTS AREAS

Throughout the study, effort was concentrated on (1) deriving EMU requirements on the basis of payload-to-EVA interfaces, (2) comparing requirements identified with previous or on-going EMU capabilities, emphasizing those with potential advanced technology development, and (3) making recommendations which are quantitative if possible, or qualitative, which reflect identified deficiencies of current EMU's to meet payload requirements.

4.1 SUMMARY OF RECOMMENDATIONS

In addition to the detailed results appropriate to each requirement area, a recommendation was considered as to appropriate disposition. Seven categories of disposition were defined as follows.

1. Standard design and development--for those requirements where data developed in the study should be sufficient for a designer, using standard practices, to accomplish a design solution.

2. Standard human engineering and physiological requirements--for those cases involving further interpretation of requirements to ensure that design solutions are appropriate to the crewman.

3. Lab testing required--some requirements could not quantified with study resources, some requirements could only be quantified as to the interface--not as to processess or materials to meet a requirement. For these requirements, laboratory testing programs are recommended.

4. Further study recommended--the probable disposition in some cases is for more in-depth study to be conducted, either in conjunction with or preceeding additional test/development activities, thus ensuring proper direction to the more costly DDT&E activities.

5. Technology development required--this group identifies those cases where state-of-the-art advancement is warranted to meet requirements areas.

6. Performance simulations recommended--for those requirement areas, primarily those which were subjective or based on estimates highly dependent on assumptions, where neutral buoyancy or Keplerian trajectory simulations are necessary to obtain precise quantitative data.

7. STS documentation/specification compatiblity--In a few cases, EMU requirements may be driven by STS documentation. It is not now clear, in many cases, whether the EMU should meet STS subsystem specifications or whether it should be treated as a payload in meeting STS requirements, nor even what these are. Possible areas of omission in this respect are identified.

Ten of the 20 requirements areas should be able to be resolved by application only of standard design practices, or with supplementary testing, standard life sciences inputs, or STS document requirements. The radiation requirement area requires a developmental study to consider physiological dose rates from all sources and which reflect crew flight schedules. In addition, lab testing and technology status of EMU protective materials are required. Four requirements need simulations in neutral buoyancy or zero-g in conjunction with other design or test activities to develop quantitative requirements data. In at least one case, bio-contamination, laboratory testing may define or rule out requirements for the EMU.

The requirements relative to reaction time appear to require (1) laboratory testing of 8-psi suits for mobility and performance characteristics, (2) a cost effectiveness study, and (3) a review for compatibility with the STS. Mobility and contamination areas require lab test data and continuing technology development. Finally, the reliability requirements need an in-depth reliability analysis and application of reliability design principles.

Table 4-1 summarizes these study recommendations.

Table 4-1. Requirement Type Recommendations Summary

Requirement Area	Standard Design Develop-ment	Standard Human Eng'r & Physio-logical Reqm'ts.	Lab Testing Recom-mended	Further Study Recom-mended	Technology Develop-ment Req'd.	Performance Simulations Recommended	STS Document/ Compatibil-ity
Crew Protection							
Flammability	X						
Thermal	X	X	X				
Durability	X		X			X	
Dielectric Prop.	X		X				X
Radiation Resistance		X		X	X		
Penetration/Abrasion	X		X	X			X
Fluid Resistance	X		X				
Impact Resistance	X		X			X	
Bio Contamination			X				
Crew Performance							
Reaction Time			X	X	X		X
Force Interfaces	X		X			X	
Mobility			X		X		
Visibility/Orientation	X	X				X	
Communication	X						X
Operating Time	X			X			
Reliability/Maintenance	X			X			
Payload Protection							
Contamination			X		X		
EMI/EMC	X			X			X
Dielectric Properties	X		X				
Surface Damage			X			X	

4.2 REQUIREMENTS REVIEW

The requirements areas were analyzed on the basis of a potentially full range of payload characteristics, mission operations, and EVA tasks. That is, planned operations, including on-orbit maintenance, and for response to payload failures (contingencies). The evaluation assumed that the crewman might interface with payloads with various systems operating and could include exposure to potential hazards. For example, the EVA crewman could operate in the vicinity of the orbiter Ku-band rendezvous radar or various payload RF sources. The crewman could be performing disconnect operations or servicing for various payload fluid systems. The EVA astronaut may be performing trouble-shooting or repair of electrical equipment requiring power-on situations (as was accomplished on Skylab). Such interfaces are defined as hazardous and are considered, as in ground operations, to be normal interfaces recognizing the higher risk. Not considered in the study are payload failure modes or accidents such as premature detonation of pyrotechnics, motor firings, high pressure system explosions, failed mechanical devices or similar modes.

4.2.1 Flammability

The review of payload characteristics and flammability criteria indicate that the EMU will not be susceptible to external sources of ignition. In order to maintain flame propagation there must be a flame supporting oxidizer and a surrounding pressure. Therefore, should the EMU be engulfed in an oxidizer, the lack of a surrounding pressure at the Shuttle orbiter altitude will not support combustion. The critical area of concern is within the EMU itself. Any EMU electrical system, must be designed and built such as not to become the ignition source internally to the EMU or the portable life support system. Since this is not a payload-derived requirement, no further analysis was conducted. Standard flammability design practices should meet any requirements.

4.2.2 Thermal

Various EVA tasks were evaluated for potential thermal interfacing with the baseline payloads. The maximum values for the majority of tasks range from 128°K (-230°F) on the low side, to 483°K (410°F) on the high side. By taking the mean and standard deviation for the task-temperatures, it was concluded that 144°K (-200°F) to 394°K (250°F) are the appropriate design-to range for natural environment. Functional temperatures will fall within a smaller range, except for fin temperatures of RTG's. For this case, 522°K (480°F) and for natural extremes, it is recommended that separate protection be applied for the few instances it is required. Follow-on recommendations indicate application of standard design and physiological principles as well as laboratory testing of thermal protective characteristics of candidate glove materials and thicknesses at these interface temperatures.

4.2.3 Durability

Evaluation of EVA tasks indicate that flexing of the EMU occurs primarily at the waist and shoulders and in the hand, wrist, and arm areas. Waist mobility is highly desirable to allow the astronaut to see around blocked areas during EVA. The waist must be substantially designed to withstand continual flexing in this

Based on estimates of EVA tasks extrapolated to the traffic model payloads, flexing cycles range from 16 to over 200 thousand cycles. Although current life cycle capability could not be determined, Apollo/Skylab "soft suits" tended to indicate early wearout characteristics. It is recommended that task simulations be conducted to establish empirical data, followed up with lab testing of the effects on various materials.

4.2.4 Dielectric Properties

EMU materials and construction must be non-conductive so as not to be painful nor injurious to EVA crewmen, damaging to payload components, and so as to prevent static potential during payload operations. Although Skylab EVA's included unscheduled repairs during power-on situations, no data were available regarding possible EMU conductivity. It should be clear, however, that the scope of orbiter payloads may increase the potential hazard to crew and to payload components. Laboratory testing of materials and identification of EMU properties in STS documentation are recommended.

4.2.5 Radiation Resistance

During EVA exposure to RTG's, the crewman would receive about 1/4 to 1/2 the allowable daily dose. Since only about 20 payload deliveries in the payload model for 1980 through 1991 would be likely to utilize the RTG, there does not appear to be a basic design requirement. However, since contingency operations may be required, special purpose protective over gloves could be a consideration.

The daily dose from Van Allen sources during one six-hour EVA period in the worst orbits could equal 30 rads, about 1/3 the 30-day allowable radiation assuming 0.3 gm/cm^2 shielding equivalent from the EMU. Although study data indicate that EVA's typically would average about 3.1 hours, conservative design should probably anticipate 6-hour EVA's. Also, statistical estimates indicate an average of 1.8 EVA's per mission. Technology research is recommended to determine EMU shielding capabilities, and to perform further analyses of the required protection so as not to exceed allowable dose limits if routine EVA is to be allowed.

Indications are that the equivalent of 0.4 to 0.45 gm/cm^2 would be desirable for routinely available EVA. Technology investigation of suitable materials with satisfactory mobility characteristics is recommended. A study of Shuttle astronaut career activities may also be required, as well as physiological inputs as to their other radiation exposures from space and atmospheric flights.

4.2.6 Penetration, Abrasion

With hundreds of spacecraft and sortie experiments being planned or developed, it appears reasonable to ensure EMU protection against various spacecraft design criteria. Manned and unmanned spacecraft standards suggest that EMU designs should tolerate at least a 0.038 cm (0.015 inch) radius as being the sharpest identified. While random burrs or screw heads are more difficult to define, laboratory investigation of material resistance is indicated. Although it would appear that protecting the EMU would be cheaper than requiring extensive radiussing of all payload edges, a cost trade may be warranted.

4.2.7 Fluid Resistance

Crew activities in support of the various payloads will require development and testing of suit materials under exposure to diverse elements such as cryogenics, hydrazine, and other propellants to establish the selection of the required suit materials.

4.2.8 Impact Resistance

Estimates are that crew translation rates could be in the order of 1 to 1.5 meters per second ($\sim$3 to $\sim$5 feet per second). Considering the mass of the suited crewman, forces in the order of 2224 N (500 lb) could be expected. If an exposed corner were encountered, with a radius of about 0.64 cm (0.25 in.), the pressure could reach 5500 N/cm^2 (8000 psi).

It is recommended that lab testing be conducted to determine the extent of damage especially to areas of the EMU such as the helmet and backpack which are hard surfaces and where the crewman's viewing may be impaired. Underwater simulations may be important to develop techniques for pushing off and for evaluating capability of the crewman to push off. It should also be noted that sharper radii may be encountered--see paragraph 3.2.6 above.

4.2.9 Bio-Contamination

Although various payloads carry organic specimens, the actual amount of biological contamination is difficult to predict due to the unknown types and quantity that might adhere to the EMU. Further research and laboratory tests appear to be in order to determine viability of various organisms in a vacuum and any necessary control techniques.

4.2.10 Crew Reaction Time

Result of previous studies indicate that operation at 8 psia will improve operations and that substantial cost savings could be attributed to quick reaction; e.g., increased experiment time in an EVA mode. The 8 psi suit offers the greatest potential for improved reaction time by elimination of prebreathing. Current technology developments for a 55 x 10^3 N/m^2 (8 psi) system are projected to equal or exceed mobility capability of previous technology 34 x 10^3 N/m^2 (5 psi) systems. Other considerations include technology risk and development costs compared to the baseline Shuttle EMU. Comparative cost analyses are required for 8 psi qualification versus cost benefits from reduced EVA response time. Continuing technology development is recommended as well as lab testing of characteristics of the higher pressure suit.

4.2.11 External Interface

Based on evaluation of EVA tasks, the crewman will frequently be required to react forces from various segments of the EMU. Primary interfaces for this force reaction will be gloves, front of waist, top and bottom of boots, front and back of lower leg, front and back of knees, and shoulders. Value of the applied force will range from about 110 to 200 Newtons (25 to 45 pounds). Simulations to validate where forces are reacted and lab tests of EMU materials (especially thermal/meteoroid garments) is recommended.

4.2.12 Mobility

The importance of EMU mobility in terms of range of motion have been recognized in recent EMU developments. Both the current Shuttle EMU procurement and the Ames suit development activities recognize the importance of these factors in performing a variety of tasks and reducing crewman fatigue. No delta requirement was found in this study. Continued technology and lab testing are recommended to maximize mobility with minimum torque.

4.2.13 Visibility/Orientation

Optical characteristics of the helmet have been thoroughly analyzed and do not present a problem. However, two payload interface problems were identified. It was concluded that the crewman has little or no visibility of the backpack assembly, and must rely on a sense of its bulk. Supporting research should be employed to determine the scope of the problem and potential design solutions such as "cat whiskers" or relocation of life support components to more visible areas. It is recommended that simulations be conducted in a backpack mode, and, if orientation problems are encountered, that life support component packaging design and location (e.g., to front or side areas) be investigated. In addition, reflectance characteristics of 85 to 95 percent of various payload surfaces indicates potential visor design requirements.

4.2.14 Communications

Voice communications will be mandatory during EVA periods. During certain periods such as spacecraft rendezvous and docking and for various payload operations, some communications interference may be encountered, unless special precautions are taken. These precautions include the insertion of appropriate true-trap filters to absorb undesirable RF energy which may be generated from such sources as the rendezvous radar or scientific RF generating equipment. In addition, special shielding may also be required for the EMU amplifier circuits for suppression of other spurious signals. It could not be confirmed that these requirements are currently imposed on Extravehicular Communications System (EVCS) design.

4.2.15 Operations Time

A statistical summary of mission EVA durations was compiled, based on the "EVA" study. The data show that all EVA's can be performed in less than 6 hours. Durations range from about 1.8 hours to just under 6 hours. The majority of EVA's, 62 percent, require less than 2.7 hours. A more uncertain area is that of contingency EVA; however, Skylab data show that of three major and several minor contingency repairs performed EVA, none exceeded 4 hours. However, further study, especially in advanced solar power station support concepts or on the basis of Shuttle/payload failure modes and effects may indicate the requirement to increase suit operating time beyond 6 to 7 hours per day. It is recommended that EMU requirements consider capbaility to extend or add to an EVA to accomplish up to 8 hours by use of kits, recharge, or perhaps modular exchange of life support units. Life support units sized at 4 hours could perform most EVA's, but could then extend EVA's easily with beneficial effects on backpack size.

4.2.16 Reliability/Maintainability

The EMU system must possess the reliability to provide the crewman with the capability to retract/safety all the applicable booms, antennas, latches, locks, and cover all optics and sensors that were designed for EVA. The EMU system must also ensure availability of the crewman to override any automated mechanism or operation which incorporates an EVA performance requirement. Current design goals have only identified crew safety as a reliability requirement. Reliability of crew response for payload manual designs should also be added as a design goal. A reliability analysis of EVA response is recommended. The reliability of the EVA system must in all cases be equal to the reliability of the automated system it is designed to replace.

4.2.17 Contamination

Primary concerns are particulates and water vapor. Since particulate adherence to optics elements in zero-g is not likely, reasonable care should be adequate. A possible design objective for materials could be to ensure that particulate diameters be <5.0 microns. Condensate control has been frequently studied. Solutions involving directional control appears to be adequate at present (i.e., rearward venting only). However, advanced development is recommended which could include positive containment with remote venting or perhaps closed systems.

4.2.18 EMI/EMC

Electrical systems of the EMU must comply with Specification SL-E-0001 (Electromagnetic Compatibility Requirements for the Systems for the Space Shuttle Program) during all phases of the Shuttle mission as specified in the EMU RFP and Specification SL-E-002 (Electromagnetic Interface Characteristics Requirements for Equipment for the Space Shuttle Program). Since EMI/EMC requirements for payloads have not been specified, further review and monitoring of STS documentation are required to ensure EMU compatibility with payloads.

4.2.19 Dielectric Properties

Considerations and recommendations are the same as for paragraph 3.2.4.

4.2.20 Surface Damage

In general, payload structured areas are not easily subject to damage by the EMU suited crewman. However, various areas of thermal coatings and fragile elements such as solar cells can be easily damaged. Since all factors of EVA interface cannot be specified, only general design requirements can be established. These include: improved mobility to maneuver about the payload, clear viewing of translation path, reduction of backpack volume (since this region cannot be seen by the crewman), padding of hard elements of the EMU, and minimal abrasive characteristics of the EMU gloves. Neutral buoyancy or other simulations of crew body handling plus lab testing of damage characteristics are recommended.